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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

A Shipyard Program for NPDES Compliance
Appendix G - Shipyard Model (PSRM-QUAL) Documentation

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

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APPENDIX G - SHIPYARD MODEL (PSRM-QUAL) DOCUMENTATION

APPENDIX G from *A Shipyard Program for NPDES Compliance*, NSRP Task N1-95-02, Applied Research Laboratory, State College, PA, July 2000

PENN STATE RUNOFF QUALITY MODEL

USER'S MANUAL

PSRM-QUAL

v95.0

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PSRM-QUAL was written with the support of the Environmental Protection Agency through The Pennsylvania Department of Environmental Resources. Their funding and continuous input to this project is greatly appreciated.

Executive Summary

PSRM-QUAL is a modification of the Penn State Runoff Model [PSRM] and has been produced under separate contracts with PA Department of Environmental Resources documented in the reports entitled "Identification of Non-Point Sources of Pollution from Urban Runoff and Modification of the Existing Computer Model: PSRM" [1992] and "Pollutant Removal Efficiencies of Detention and Infiltration Facilities" [1994].

Quantity Model

The following modifications have been made to the previous PSRM algorithms for prediction of runoff quantity.

- A sequence of up to eight consecutive storms is allowed.
- The kinematic wave equations are used to predict "cascading" overland runoff.
- In previous versions, a uniform depth and runoff rate were determined for the entire subarea. PSRM-QUAL has water depth and velocity increasing as the runoff proceeds down through the subarea to the storm water collector.
- Infiltration is computed as a function of the accumulated water content in the soil. Also, a deep percolation function was added to remove water to an underlying aquifer. In previous PSRM models, the SCS runoff equations were used which resulted in an abrupt stop in infiltration the moment precipitation started.

Quality Model

A literature review, along with field and laboratory studies were conducted in order to identify the most appropriate algorithms for the PSRM-QUAL model. Some important conclusions from the literature and experimental studies are as follows.

- Contaminants in urban runoff are predominantly associated with dust and dirt particles. Relationships between particle sizes of dust and dirt and contaminant concentrations were determined.

- Small particles are most important because they are most numerous and because they have higher concentrations of contaminants than larger particles. Contaminants attached to very small particles may be transported as if the contaminants were dissolved.
- Removable particles are rapidly washed from surfaces. The rate of removal was investigated and is a function of the size of the particle, the rainfall intensity, and the computed flow velocity.

Mobilization and transport of pollutants in the model are determined according to the following algorithm.

- Drainage areas consist of pervious and impervious zones. All contaminants are associated with particles and are removed in relation to the loosening and wash off of the particles.
- Particles in impervious areas are loosened by rainfall. Dislodging of particles is a function of the rainfall intensity and the concentration of particles remaining to be washed off.
- Particles in impervious areas are transported by overland flow only when the kinematic velocity exceeds a value necessary for suspension on the particle (a function of particle size, density and drag coefficient).
- Particles in pervious zones are released and washed off according to the Universal Soil Loss Equation. Contaminants that are associated with the eroded soil particles are also swept into the surface runoff by this mechanism.
- Particles in overland flow or channels are transported at a velocity that is less than the water velocity, again due to drag functions.
- Pollutant buildup between storms is permitted for impervious areas. An inexhaustible supply of erodible particles and contaminants are assumed for pervious areas.

Priority Pollutants

Total suspended solids (TSS) are the most important pollutants for modeling purposes, since all other contaminants are associated with the particles. Trace metals have the greatest impact on streams, therefore copper (Cu), lead (Pb), and zinc (Zn) are included. Nutrients are especially important for waters susceptible to eutrophication and therefore total phosphorus (TP), soluble phosphorus (SP), total kjeldahl nitrogen (TKN) and Nitrates and Nitrites (NO_2 and NO_3) are considered in PSRM-QUAL. Also COD and BOD concentrations are predicted by PSRM-QUAL. For NPDES permit applications, EPA has placed some emphasis on trace organic materials. Accordingly, PSRM-QUAL can analyze up to two user defined, conservative trace organic materials, which may include oil and grease.

BMP Model

The capability of evaluating structural best management practices (BMPs) is the most recent addition to PSRM-QUAL. Six types of BMPs can be modeled, namely, dry detention basins, dry extended detention basins, wet basins, constructed wetlands, infiltration basins and infiltration trenches. A literature and data search was performed in an effort to identify key removal processes and associated algorithms for these facilities. The following results were obtained.

- For suspended solids removal (and therefore conservative pollutants), the mechanisms of grass filtration, settling and resuspension were identified as key removal mechanisms.
- For dissolved pollutant removal, a first order decay relation was adopted for the major removal process. The pollutants of TKN, NO_2+NO_3, TP, SP, COD and BOD are considered to be all or partially dissolved in the BMP routines. Dissolved fractions are defined for each of these pollutants.
- Conservative pollutants (TSS, Cu, Zn, Pb and trace organics) will remain associated to total suspended solids (TSS) during the routing of sediments through a BMP.
- Dissolved fractions of the pollutants TKN, NO_2+NO_3, TP, SP, COD and BOD, will not remain associated to TSS once a BMP is encountered in the watershed system of subareas.
- For the special case of infiltration facilities, removal was assumed to be completely a function of mass balance. For time intervals when surface runoff is trapped by the facility, 100% of the sediments are assumed trapped. During time intervals when runoff overflow occurs, all sediments associated to the

overflow runoff rates are prorated according to runoff into and out of the facility.

- The previous version of PSRM-QUAL differentiated pollutant association with varying particle size. However, a thorough review of NURPS quality data revealed that the pollutant association relations based on varying particle size used in PSRM-QUAL were not consistent with NURPS data. This required the removal of particle size related association factors, since no such field data exists in the literature.

BMP algorithms were to be calibrated prior to release for general use. Unfortunately, the literature and data search of the BMP study revealed that insufficient data of type and quality needed to perform a calibration for the algorithms are not currently available. *Because of this fact, the user of the BMP routines within this model are strongly encouraged to collect the necessary data and perform a calibration of the model before it is used in a modeling mode.* Results obtained with this model without the benefit of calibration will be very difficult, if not impossible, to interpret.

System Requirements

PSRM-QUAL can be run on any IBM compatible personal computer with CGA (or compatible) graphics card, 640 KB RAM, a hard drive with MS-DOS version 5.0 or greater. A 486 DX or better processor and a color monitor are strongly recommended for convenient operation.

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List of Symbols

Symbol	Variable	Definition	Subroutine
α	IFHSS	Infiltration Facility Horizontal component of Side Slopes	Infil. facility
η		Exponent defining flow regime	Overland runoff
ν		Kinematic viscosity of the water	Grass filtration
Ψ		Sediment characteristic which varies with particle size, lb/cuft-sec	Resuspension
τ_i		Critical tractive stress exerted on the bed, lb/sqft	Resuspension
γ, γ_w		Specific weight of water	Overland runoff
γ_s		Specific weight of sediment	Pollut. washoff
A		Cross-sectional flow area, sqft	Overland runoff
AREA		AREA of the subarea, acres	Overland runoff
A_u		Computed soil loss, metric tons/hectare	Pollut. dislodging
b		Loading coefficient, 1/day	Pollut. buildup
	BOTEFL	BOTtom EFfective Length, ft	Resuspension
	BOTEL	BOTtom ELevation of basin, ft	Sedimentation
	BOTMN	BOTtom Manning's N value	Resuspension
	BOTSLP	BOTtom (friction) SLoPe, ft/ft	Resuspension
	BTYP	Bmp TYPe	
c	IAF	Initial Abstraction Factor	Infiltration
	CAP	CAPacity of the drainage element, cfs	Stream/pipe flow
C_d	CD	Coefficient of Drag.	Pollut. washoff
	CDE	Connecting Drainage Element	Hyd. Addition
CF		Soil capacity filled	Infiltration
C_f	DFC	Dynamic Friction Coefficient	Pollut. washoff
CF_o/S_c	IFSW	Initial Fraction of Soil Wetted	Infiltration
CN	CN1	Curve Number for impervious areas.	Infiltration
CN	CN2	Curve Numbers for pervious areas.	Infiltration
C_o		Pollutant concentration at time zero	Pollut. decay
C_s	SFC	Static Friction Coefficient.	Pollut. washoff
C_t		Pollutant concentration at time t	Pollut. decay
	CTS	Channel To Surface velocity ratio	Stream/pipe flow
C_u	UC	Universal soil loss equation C factor	Pollut. dislodging
	CWWDTH	Constructed Wetland characteristic WiDTH	Const. wetland
	CWYINI	Constructed Wetland (Y) INItial depth of flow	Const. wetland
d		Deep percolation function	Infiltration
d		Particle diameter, ft	Sedimentation
D		Depth of flow, ft	Resuspension
d_f		Depth of flow, ft	Grass filtration
d_{ij}		Distance between gages j and centroid of subarea i	Hyetograph
d_m		Mean diameter of the sediment in the basin bed, millimeter	Resuspension
	DS1	Depression Storage for impervious areas, inches	Losses

Symbol	Variable	Definition	Subroutine
	DS2	Depression Storage for pervious areas, inches	Losses
DT		Detention time, hr	Sedimentation
F		Cumulative infiltration, inches	Infiltration
f		Infiltration capacity, in/hr	Infiltration
f_c		Equilibrium infiltration rate, in/hr	Infiltration
f_o		Maximum infiltration rate, in/hr	Infiltration
	FRIMP	Fraction of area IMPervious	Overland runoff
F_x		Summation of forces in x-direction	Overland runoff
g		Gravitational acceleration constant	Overland runoff
	GRHGT	GRass HeiGhT of BMP bottom, inches	Filtration
g_s		Bed load in pound of foot per width	Resuspension
h		Local depth of water, ft	Sedimentation
	HEAD	Falling HEAD, ft	Infilt. facility
	HTSL	Hydrograph Total Sediment Load, lb	Pollut. transport
	HTYP	Hydrograph TYPe	Observed Hyd.
H_w		Average hydraulic head, ft	Infiltration basin
	HYDNPT	HYDrograph Number of PoinTs	
	HYDTI	HYDrograph print Time Interval, minutes	
I		Inflow rate, cfs	Stream/pipe flow
i		Lateral inflow or rainfall excess	Overland runoff
i		Rainfall intensity, in/hr	
IA		SCS initial abstraction	Infiltration
	IENPT	Inter-Event Number of PoinTs	
	IETI	Inter-Event Time Interval, minutes	
	IFDPTH	Infiltration Facility DePTH, ft	Infil. facility
	IFGEOM	Infiltration Facility GEOMetry	Infil. facility
	IFPOR	Infiltration Facility POROsity	Infil. facility
I_h		Infiltration rate as a function of hydraulic head, in/hr	Infiltration basin
	INFIL	INFILtration rate, in/hr	Infil. facility
	ISL	Initial Sediment Load, grams/curb-meter	Pollut. dislodging
	IWSE	Initial Water Surface Elevation	Res. routing
k		Decay coefficient	Pollut. decay
k	SBK	Sartor-Boyd K value (dislodging coefficient), 1/inch	Pollut. dislodging
k		Infiltration rate decay coefficient, 1/minute	Infiltration
K_m		Storage time constant for the reach	Stream/pipe flow
K_s	KS	Saturated hydraulic conductivity, K_S, in/hr	Infiltration
K_u	UK	Universal soil loss equation K factor	Pollut. dislodging
	KWTI	Kinematic Wave Time Interval, minutes	Overland runoff
L	CWBEFL	Constructed Wetland Bottom EFfective Length	Const. wetland
L_b	IFBLEN	Infiltration Facility Bottom LENgth, ft	Infil. facility
LENG	LENG	LENGth of the characteristic flow path, ft	Overland runoff
Ls		Element length through subarea	Overland runoff
LS_u		Slope-length factor.	Pollut. dislodging
	LU	Land Use	Sediment loading
M		Mass of water in control volume	Overland runoff

Symbol	Variable	Definition	Subroutine
m_1		Mass of lateral inflow.	Overland runoff
	MINRATE	MINimum infiltration RATE, in/hr	Infil. facility
N		Amount of particles of a given size range which may remain on the impervious surface at time t	Pollut. dislodging
n	MN1	Manning's N value for impervious areas	Overland runoff
n	MN2	Manning's N value for pervious areas	Overland runoff
n	CWBMN	Constructed Wetland Bottom Manning's N	Const. wetland
n	SCN	Short Circuiting Number	Sedimentation
	NBMP	Number of subareas with BMP	
N_c		Amount of particles of a given size range which are dislodged during a time interval	Pollut. dislodging
	NCDE	Number of Connecting Drainage Elements	Hyd. addition
	NESO	Number of Elevation-Storage-Outflow points	Res. Routing
	NFHP	Number of Falling Head Points	Infil. facility
	NHL	Number of Heading Lines in the file definition block	
	NNRG	Number of Non-Recording Gages	Gage weighting
N_o		Initial loading intensity of the material of a particle size range which could be loosened by a given rainfall intensity.	Pollut. dislodging
	NOBS	Number of subareas with OBServed (or inflow) hydrographs	
	NOHO	Number of Observed Hydrograph Ordinates	Observed hyd.
	NORG	Number of user identified ORGanic pollutants	
	NPFP	Number of subareas with Peak Flow Presentations	
	NPRT	Number of subareas with PRinTed output	Hyd. printing
	NRES	Number of subareas with REServoirs	
	NRG	Number of Recording Gages	Gage weighting
	NSA	Number of SubAreas	
	NST	Number of STorms	
	NWG	Number of Weighting Gages	Gage weighting
O		Outflow rate, cfs	Stream/pipe flow
O_2		Basin exfiltration outflow, cfs	Infiltration basin
	ORGCONC	ORGanic CONCentration, microgram/gram of total solids of sediment	
	ORGNME$	ORGanic NAME	
P		Cumulative precipitation, inches	Infiltration
P_e		Effective precipitation, inches	Infiltration
P_{max}	MSL	Maximum Sediment Load, gram/curb meter	Pollut. buildup
P_R		Surface pollutant load at a particular time, gram/curb meter	Pollut. buildup
PT		Pipe or channel travel Time, minutes	Stream/pipe flow
P_u	UP	Universal soil loss equation P factor	Pollut. dislodging
Q		Cumulative runoff depth (SCS runoff equation)	Infiltration
q		Discharge per unit width, cfs/ft	Overland runoff
	QBYP	Flow (Q) BY-Pass, cfs	Routing / BMP

Symbol	Variable	Definition	Subroutine
Q_{max}		Maximum outflow rate from the basin during the event, cfs	Sedimentation
r		Median particle radius, ft	Pollut. washoff
R_1	IFBDIA	Infiltration Facility Bottom DIAmeter, ft	Infil. facility
R_2		Top radius of the basin, ft	Infiltration basin
R_d		Fraction of solids removed under dynamic conditions	Sedimentation
	REGION	Pennsylvania storm REGION for PDT-IDF synthetic storm	Synthetic rainfall
	REMOPT	REMoval OPTion	BMP
	RETPRD	RETurn PeRioD of the storm	Synthetic rainfall
	RFDIST	RainFall DISTribution for SCS synthetic storm	Synthetic rainfall
	RFDPTH	RainFall DePTH, inches	Synthetic rainfall
	RFNPT	RainFall Number of PoinTs	Synthetic rainfall
	RFTI	RainFall Time Interval, minutes	Synthetic rainfall
	RGNAME$	Rain Gage NAME	Gage weighting
	RGST	Rain Gage Start Time, minute.	Gage weighting
R_s		Spacing hydraulic radius, ft	Grass filtration
	RTYP	Reservoir TYPe	Res. routing
S		Storage (tributary or reservoir), cuft	Stream/pipe flow
S	CWBSLP	Constructed Wetland Bottom (friction) SLoPe	Const. wetland
S	SLOPE	SLOPE of the characteristic flow path, ft/ft	Overland runoff / Pollut. washoff
S_c		Soil storage capacity, inches	Infiltration
Sc	GRSPCG	GRass SPaCinG of the BMP bottom, inches	Grass filtration
S_f		Friction slope	Overland runoff
SF		Sinuosity Factor	Overland runoff
SG		Specific gravity of sediment	Pollut. washoff
S_o		Slope of plane or channel, ft/ft	Overland runoff
	STGDIM	STaGe DIMension	Filtration / sedimentation
	STOPT	STorm OPTion	Synthetic rainfall
	SWFR	SWeeping Fraction Removed	Sediment loading
	SWST	SWeeping Start Time, hr	Sediment loading
	SWTI	SWeeping Time Interval, days	Sediment loading
t		Time	
T_r		Fraction of sediment trapped by vegetation	Grass filtration
u		Lateral inflow velocity in x-direction, fps	Overland runoff
v, v_w		Local velocity, fps	
	VBOTSED	Volume of BOTtom SEDiments, cuft	Resuspension
V_{max}		Maximum detention volume of the basin during the event, cuft	Sedimentation
v_s		Sediment velocity for a given particle size, fps	Pollut. washoff
v_s		Particle settling velocity, fps	Grass filtration
W_b	IFBWDTH	Infiltration Facility WiDTH, ft	Infil. facility
WTij		Weighting factor of gage j and subarea i	Gage weighting
x		Overland distance, ft	Overland runoff

Symbol	Variable	Definition	Subroutine
XCG		X coordinate of the subarea "Center of Gravity"	
X_m	MX	Muskingum X coefficient	Stream/pipe flow
XRG		X coordinate of Rain Gage	
y		Depth of flow, ft	Overland runoff
YCG		Y coordinate of the subarea "Center of Gravity"	Gage weighting
YRG		Y coordinate of Rain Gage	Gage weighting

1

INTRODUCTION

1.1 Stormwater Management Modeling

Many hydrologic models have been developed over the past three or four decades to simulate stormwater runoff under varying management practices. Most of the computer models presently in use are confined to purely hydrologic simulations, but some models, like EPA SWMM [Huber et al., 1981], have for several years included runoff quality algorithms.

Stormwater quality problems are the result of non-point source pollution, which is usually very difficult to quantify. Non-point source pollution occurs in the form of road-salt applications, heavy metal and organic compound deposition from automobile and industrial exhaust fumes, and decaying matter from many sources. Contrary to point-source pollution from a specific outfall, which can be monitored closely, non-point source pollution must usually be associated indirectly with windblown or eroded sediments of various size ranges. The pollutant content of these sediments, in turn, can depend heavily on the local climate and the industrial activities of the particular community. Pollutant buildup has been measured and published by various investigators such as Novotny and Chesters [1981]. As a consequence, these relatively sparse published data are used as general estimation parameters. This generalization is a risky practice. *Users of any stormwater pollution model should always be aware that there is no satisfactory substitute for locally monitored data.*

To estimate non-point source pollution in stormwater runoff, the processes for particle buildup, managed removal, and washoff must be modeled. Algorithms of this type have been developed and proposed by several investigators, such as Huber et al. [1981] and Sartor and Boyd [1972], and appropriate algorithms have been adopted in this model.

1.2 Objectives

While recognizing the extreme complexity of the complete non-point pollutant buildup and washoff process, it must also be kept in mind that any model intended for practical use must be simple enough that it can be used by public agency personnel and private consultants without expensive site-specific monitoring programs. The objective of this model is to strike an acceptable compromise of simplicity and adequate reliability of the quantitative and qualitative model output.

1.3 The Penn State Runoff Model (PSRM) - Background and Development

Several editions of the PSRM mainframe program were developed between 1976 and 1984. During this time, PSRM has steadily gained acceptance as a rainfall-runoff model by regulating agencies in the United States as well as in other countries. In 1986, PSRM was rewritten in IBM-compatible BASIC for use on increasingly popular IBM compatible personal computer. The model was reorganized for more efficient memory use and some options were added. The model could be run for up to 72 subareas and 72 time intervals. The 1990 version of PSRM, compiled in Microsoft Quick BASIC version 4.5, allowed the user to specify the array sizes (dynamic arrays) for the number of subareas and time intervals. The product of the subarea and time interval array sizes could be as high as approximately 12,000.

In the 1990's there was an increased awareness of environmental issues. The polluting of streams became a dilemma which had to be addressed. Therefore, in 1991, PSRM was modified to include a non-point source pollutant transport algorithm to estimate pollutant concentrations in the runoff. The model name was modified to PSRM-QUAL to reflect this major change.

The runoff method of PSRM has been improved in PSRM-QUAL. In the older program of PSRM, a hydrograph is formed for each subarea in one overland step. A multiple overland step or "cascade" procedure was developed for PSRM-QUAL to produce a gradual buildup of runoff depth as runoff travels down the subarea. PSRM, simulates overland runoff by assuming the buildup of a sheet of water of uniform depth over a subarea and then computing the runoff rate as a function of depth and width of runoff sheet flow by the laminar or turbulent flow equations.

The uniform depth buildup assumption was necessary due to the limitations in memory space in the old interpreter BASIC (BASICA, GWBASIC) programming language. Since the adoption of QuickBASIC, more memory was available and a more rigorous kinematic wave algorithm could be developed. The algorithm simulates the runoff and pollutant transport as a cascade of sheet flows from consecutive terraces along the flow path. The model includes overland, tributary, surcharging (excess runoff beyond main channel capacity) and observed hydrograph input. These routines are needed for the quality estimates to produce sediment graphs. Once a sediment graph (TSS) has been developed, the priority pollutants such as trace metals, nutrients, and organic material, may be estimated.

The hydrologic program PSRM was a single storm event model. This was adequate for the purpose of synthesizing design hydrographs or runoff peaks. In the simulation of pollutant buildup and washoff, however, consecutive storm bursts, spaced a few hours or days apart, play a major role and must be considered. Likewise, the recovery of infiltration capacity between storm bursts cannot be ignored. Table 1.1 provides a summary of the major modifications made to PSRM in the process of developing PSRM-QUAL.

Table 1.1 Summary of main additions to PSRM in the creation of PSRM-QUAL.

1. Kinematic wave method for overland flow
2. Multiple storm input capabilities
3. Deep percolation added to infiltration equation
4. Non-point source pollutant prediction
5. Pollutant removal by best management practices (BMPs)

It should be noted that previous research on pollutant concentrations in stormwater runoff is limited. Many of the non-point source pollutant models which exist today are based on the results of a few field tests. This model considers only suspended pollutants and currently does not directly consider dissolved pollutants as such. One goal of this model, therefore, is to open avenues for future research of this type. The algorithms and parameters used in PSRM-QUAL are not to be considered without flaw and will continue to be modified and improved as new literature, data and experiences accumulate.

2

FILES, INSTALLATION AND PROGRAM OPTIONS

2.1 System Requirements for PSRMQ95

PSRM-QUAL can be run on any IBM compatible personal computer having a minimum of 640K conventional memory and a hard drive with MS-DOS version 5.0 or greater. An Intel 486© based computer along with a color monitor is strongly recommended. The program is written and compiled in Microsoft QuickBASIC.

2.2 Program Files

The entire set of program files fit on one 3 1/2" high density diskette and consists of several executable (EXE) program files and supporting data (DAT) files. Executable files contain the computer language code developed for the model which are compiled into machine readable code to increase computational speed and provide code security. PSRM-QUAL consists of the EXE files listed in Table 2.1.

Table 2.1 Executable files of PSRM-QUAL

Executable File		Function
BRUN45.EXE	-	Microsoft utility file needed for program operation.
PSRMQ.EXE	-	start-up program
PSRMQ95.EXE	-	main menu program
XINPUT.EXE	-	data file reorganization program (transparent to the user)
XOPT1.EXE	-	data input file creation program
XOPT3.EXE	-	runoff and quality computations program
XOPT4.EXE	-	data plotting program (not running at this time)

Past versions of PSRM-QUAL contained the EXE files OPT2.EXE, file listing and OPT5.EXE, file modify. This version of PSRM-QUAL removes the need for these two EXE files by utilizing the DOS program EDIT.

2.3 Supporting Files

Supporting files are provided to give the user the opportunity to change key parameters and coefficients used in the quality routines. Because of the nature of runoff quality modeling, the modification of these files will most likely be necessary to get reasonable results from PSRM-QUAL for site specific conditions. The supporting files for PSRM-QUAL are as follows.

Table 2.2 Supporting Files for PSRM-QUAL

Support File		Description
DECAY.DAT	-	dissolved pollutant decay coefficients and dissolved fractions for removal in BMPs
POLC.DAT	-	pollutant association factors for each pollutant, curb density, and pollutant build-up factors; for each landuse impervious areas.
PSDIST.DAT	-	particle size definition and distribution for several stages of sediments in the transport and removal process.
REMRATES.DAT	-	pollutant removal rates for detention facilities when the default option 1 is used.
STDPARAM.DAT	-	standard parameter default values to assist in user data entry.

Each supporting data file will be discussed in greater detail in the quality modeling section of this manual. All users are strongly encouraged to review the content of each of these files and verify that the contained data reasonably reflect the conditions of the watershed. To run the model without first checking and adjusting these values to specific watershed conditions is inadvisable.

2.4 Input and Output Files

PSRM-QUAL uses the DOS file name extension to differentiate between data input files and data output files. The extension ".INP" is used for input files and the extension ".OUT" is used for output files. These extensions are automatically added to the file at the time of creation by PSRM-QUAL. These are the only types of files created by the program .

2.5 Installation

Before installing the software, make a backup copy of the program diskette using the DOS command DISKCOPY. This will be particularly important once you begin editing the contents of the supporting DAT **files. These files <u>must</u>** maintain a certain format in order to remain readable for the EXE program files.

Installation of the program is not difficult although there is no install program. On your hard drive create a home directory for PSRM-QUAL (consult your DOS manual for assistance in using the MD command). For the purpose of discussion, the directory name of PSRMQ will be used here. All necessary files for the program operation are contained on one 3 1/2" high density diskette. Copy these files into the PSRMQ directory (consult your DOS manual for assistance in using the COPY command). The following sequence of DOS commands (in bold type) would be necessary if the program diskette was inserted in the A drive of your computer.

C:\>**MD PSRMQ** - *make the directory PSRMQ*

C:\>**CD PSRMQ** - *change from the root directory to the PSRMQ directory*

C:\>PSRMQ **COPY A:*.*** - *copy all files on the A diskette to the directory*

C:\>PSRMQ

In order for option 2 of the Main Menu of PSRM-QUAL to function, the MS-DOS EDIT program must be present and accessible on the hard drive of the computer. Make certain that the CONFIG.SYS file of your computer has a PATH statement containing the directory where the MS-DOS EDIT program resides (usually in the DOS directory).

2.6 Starting the Program

Make sure that you are in the PSRMQ directory. At the command prompt, type PSRMQ and press enter. This initiates PSRMQ.EXE which is simply a start-up program with a user warning screen, indicating that as much site specific data as possible should be placed in the supporting DAT files and that calibration of the model is very important. Pressing any key will cause PSRMQ.EXE to end and pass program control to PSRMQ95.EXE which is the Main Menu of PSRM-QUAL. The six options available to the user are listed on the Main Menu screen.

2.7 Option 1: Create a New INP File

This option must be used to create an INP file for input into Option 3. This routine sequentially prompts the user for the required data and then writes the data to an INP data file. The file name (eight characters or less) is specified by the user. Primitive screen by screen data edit features are available in this routine, however touch-up editing can be performed with greater ease using the full screen editor available in Option 2. The user may create a "quantity only" file or a "quantity and quality" file. The "quantity only" file allows the user to use PSRM-QUAL in a runoff only mode similar to PSRM without the need for entering all of the quality related parameters.

Program PSRM-QUAL, like its predecessor PSRM, uses a sequential numbering system for subareas and drainage elements. Prior to creating an INP file, the user should be fully knowledgeable about the rules for subdividing the watershed, the number of rainfall events, use of rainfall options, hydrograph span time(s), assigning runoff/pollutant parameter values, the size (or preliminary size) of conveyance drainage elements, and any subarea options such as observed hydrographs, detention ponds or BMPs. All of these topics are discussed in detail in later portions of this manual. The sequence of data input in the file create option is presented in detail in Chapter 6, "Input File Create Instructions".

2.8 Option 2: MS-DOS EDIT

The MS-DOS full screen editor, EDIT is accessed in a shelled environment through this option. PSRMQ95 remains resident in computer memory, but the EDIT program is temporarily accessed to perform data file editing, review or printing. Upon exiting the EDIT program, the user is returned to the PSRMQ95 Main Menu.

EDIT is fundamentally the same as the Microsoft WORD for DOS (version 5.0 or later) word processor and the Microsoft QuickBASIC code editor. If you are familiar with either of these programs, then EDIT will be very easy to use. For unfamiliar users, the specifics on the use of EDIT are contained in your MS-DOS users manual.

2.9 Option 3: Run PSRM-QUAL

To use this option, an INP file must first be created through Option 1. Upon selection of this Option 3, the user must enter the path of the data drive (A, B, C, etc.) and enter the name of the desired INP file. The names of all available INP files for the specified data drive are displayed on the screen for user reference. The name should be entered without the file extension.

After file selection the program reads the INP file. The user is presented with the option to change the OUT file name (default is the same as the INP file name, with the extension being change from INP to OUT). After OUT file name entry, the program presents a small run-time option menu that includes (1) sensitivity analysis, (2) quantity only calculations, and (3) quantity and quality calculations.

The sensitivity analysis option allows the user to enter seven parameter adjustment factors, namely, **XLENG, XSLOPE, XMN1, XMN2, ACN1, ACN2** and **AIAF**. The X parameters are multiplication factors which will be applied to the related parameters in all subarea calculations. Thus the value of **LENG** (characteristic overland flow length) for each subarea will be multiplied by **XLENG** prior to runoff calculations. The other X affected parameters are **SLOPE** (overland slope for surface runoff), **MN1** (impervious area Manning's n value for surface runoff) and **MN2** (pervious area Manning's n value for surface runoff). In a similar fashion, the A parameters are addition (+/-) parameters that will be applied to their related parameters of **CN1**(impervious area curve number), **CN2** (pervious area curve number), and **IAF** (initial abstraction factor). This run-time option allows the user to run parameter sensitivity analyses for a particular watershed without the need for changing the INP file content. Upon selection of this run-time option, the user will be presented with a screen very similar in structure to those contained in Option 1, through which the sensitivity parameters can be entered. The value of these parameters are not recorded permanently by the program. The user must keep track of these values if they are needed.

The other two run-time options obviously require the INP file to be one containing runoff quantity and quality parameters. If the INP file contains quality data, the user has the option to run the INP file without calling the quality routines, thus giving only runoff quantity output. This option is inaccessible by the user if the INP file contains only runoff quantity parameters.

Once the user has passed the run-time portion of Option 3, the program begins the serious task of calculating runoff and pollutant quantities for each subarea. The nested loop structure of the runoff computation code is primarily described as "For every subarea..., For every storm..., For every kinematic cascade length..., For impervious/pervious areas..., For every hydrograph ordinate..., For every kinematic wave time interval..., and then back out of the nested loops until computations are complete. Inter-twined in the runoff computation code are decision points where runoff quality routines are executed if called. These runoff quality routines are pollutant buildup, sediment dislodging, sediment wash-off, pollutant association, and pollutant removal by BMPs.

At the end of every subarea computation loop, several routines are called if appropriate. These routines are (1) route hydrograph through reservoir type 1, (2) add observed/inflow hydrograph, (3) add upstream subarea hydrograph(s), (4) route hydrograph through reservoir of type 2, (5) route hydrograph/pollutographs through a BMP, (6) compute surcharge hydrograph, (7) print hydrograph and pollutograph to OUT file and (8) route hydrograph through downstream drainage element. At the end of all computations, the program prints a summary table of peak flows and TSS event mean concentrations for all subareas. The flow charts of Figure 2.1 and Figure 2.2 summarizes the computation process present in Option 3.

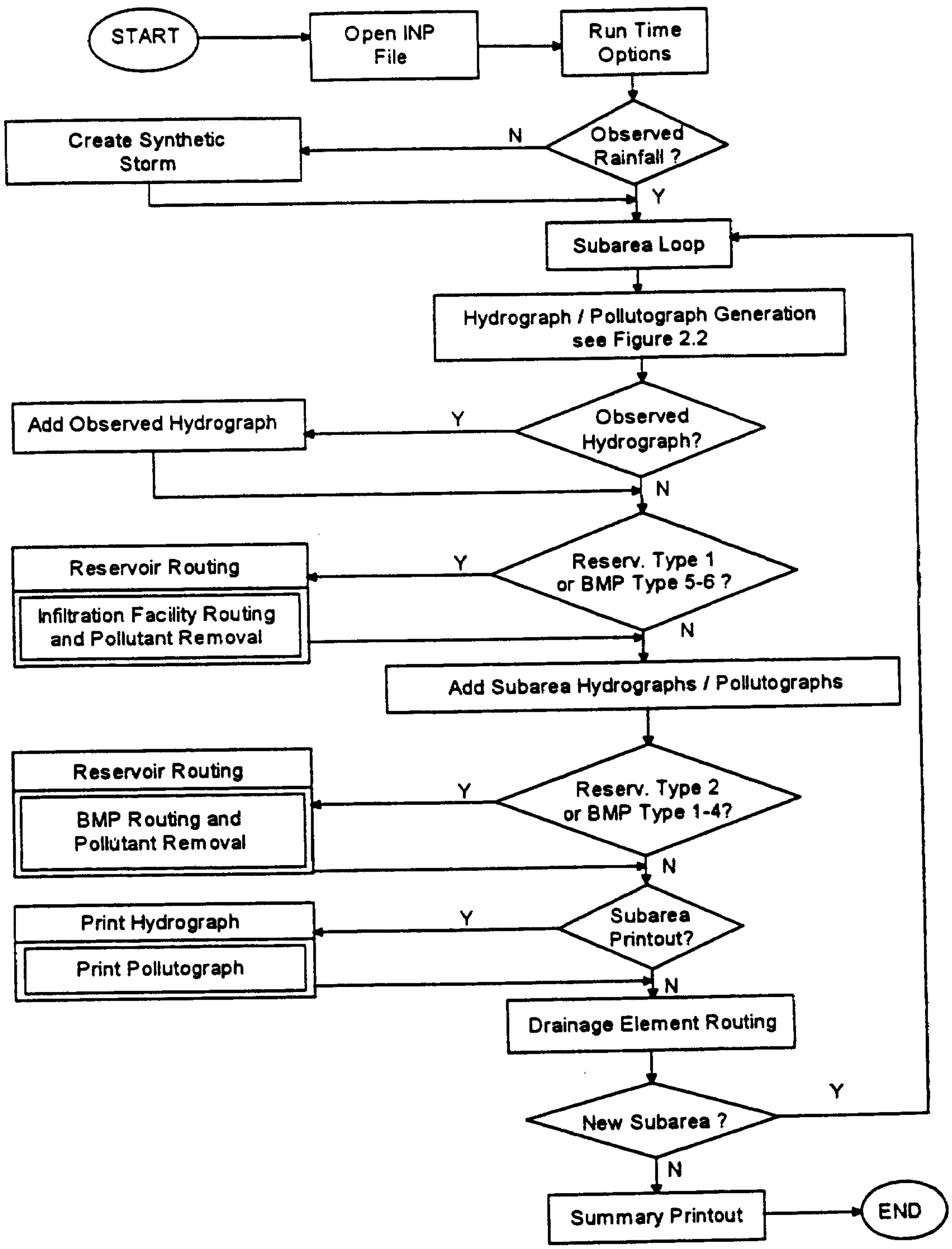


Figure 2.1 Flow chart of PSRM-QUAL.

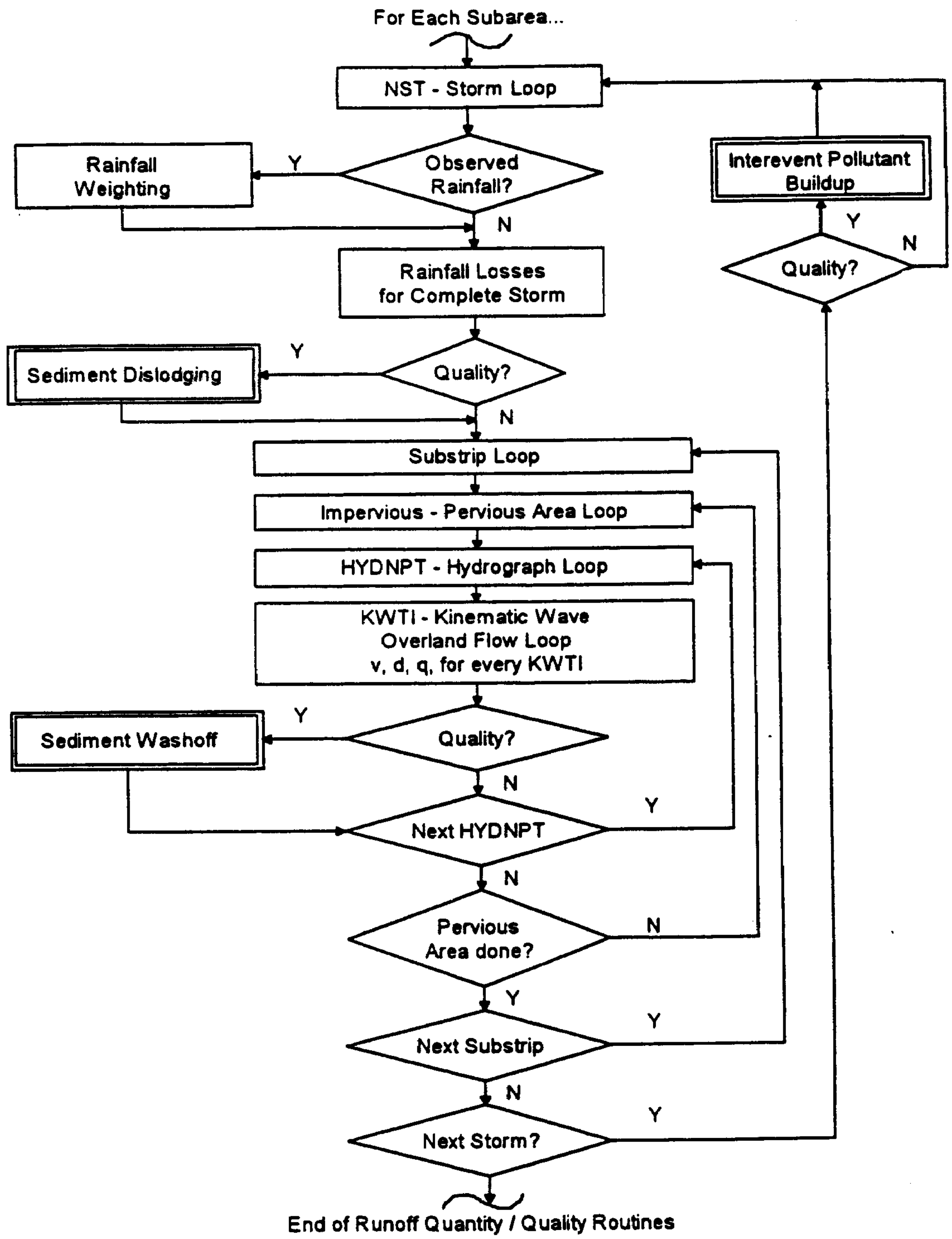


Figure 2.2 Flow chart of the runoff quantity and quality routines (hydrograph and pollutograph generation) of PSRM-QUAL.

Program output is not displayed on the computer monitor during Option 3. All output is sent directly to the OUT file. To review the output the user must select Option 2 from the main menu and open the OUT file using EDIT. From within edit, the user may print the file for hard copy.

2.10 Option 4: Plot OUT file results

At the time of the writing of this manual, this option had not been updated to accommodate the changes made to the OUT file structure for the necessary inclusion of BMP output. Therefore this option does not presently work. Users of commercial spreadsheet packages will most likely use the superior plotting capabilities of these packages to plot the PSRM-QUAL OUT file results. Appendix B "Plotting OUT File Data Using LOTUS 123 or Microsoft EXCEL" is provided for those users who have access to LOTUS 123 and Microsoft EXCEL but are not familiar with the plotting routines in the commercial software.

2.11 Option 5: Shell to DOS

This option is made available to the user who wishes to shell to the DOS environment while still maintaining PSRMQ95 active in memory. This is convenient if the user wishes to check the content of a directory, such as a file name or file data, before progressing to other options. A DOS shell will send the user to the DOS command prompt. Type EXIT at the command prompt to return to the Main Menu.

2.12 Option 6: Quit

Use this option to exit PSRMQ95. PSRM-QUAL will be removed from computer memory and computer control will be returned to the DOS command prompt.

2.13 EXE Program Failure

It is possible that an unexpected fatal error could occur at any time during the use of PSRM-QUAL, depending on the appropriateness of input data. In the event that you encounter such an error, the program will return you to the DOS command prompt (referred to as system by the computer). To restart the program simply type PSRMQ95 at the command prompt and press enter. Encountering such an error will destroy all computations made to that point. Check your data input file for correct form before running the program again.

3

DETAILS OF OVERLAND FLOW QUANTITY MODELING

The overland flow runoff routines in PSRM-QUAL have been changed as compared to the predecessor PSRM (see executive summary). However, the tasks that must be performed by the user to run PSRM-QUAL are very similar to those necessary to run PSRM. Prior to building a data file, the user must subdivide the watershed into relatively homogeneous runoff catchments and define the associated drainage network. Subarea based runoff parameters necessary to characterize the runoff conditions must be determined. In addition, the desired rainfall event(s) must be chosen and the associated data collected for input. The following sections of this chapter explain the process for watershed discretization and the details of the runoff routines in the model. Figure 2.2 shows the flow chart of the runoff quality and quantity routines for PSRM-QUAL.

3.1 Watershed Subdivision

The first task, prior to generating a data file, is the subdivision of the watershed. Two alternative subdivision schemes are illustrated in Figures 3.1 and 3.2. As a first step, the major drainage paths should be identified. These paths may be the trunk sewers or they may be collector streams or swales. Beginning near the upstream end of the watershed, one of these paths is chosen as the main stream and divided into convenient segments, referred to from here on as drainage elements. The drainage elements must be labeled consecutively until a junction is reached, at which time the incoming tributary is divided into consecutively numbered elements. Below a junction, the numbering continues, again stopping on the way to pick up incoming tributaries.

The next step is to subdivide the total drainage basin into subareas. In the scheme outlined in Figure 3.1, a subarea boundary line is drawn out laterally from each of the drainage path segmentation points, in such a way that each drainage element corresponds to one and only one subarea immediately upstream. The subarea and corresponding outfall drainage elements are labeled by the same number. Some subareas (in this case 5, 6, and 11) may have 2 or 3 upstream drainage elements crossing it.

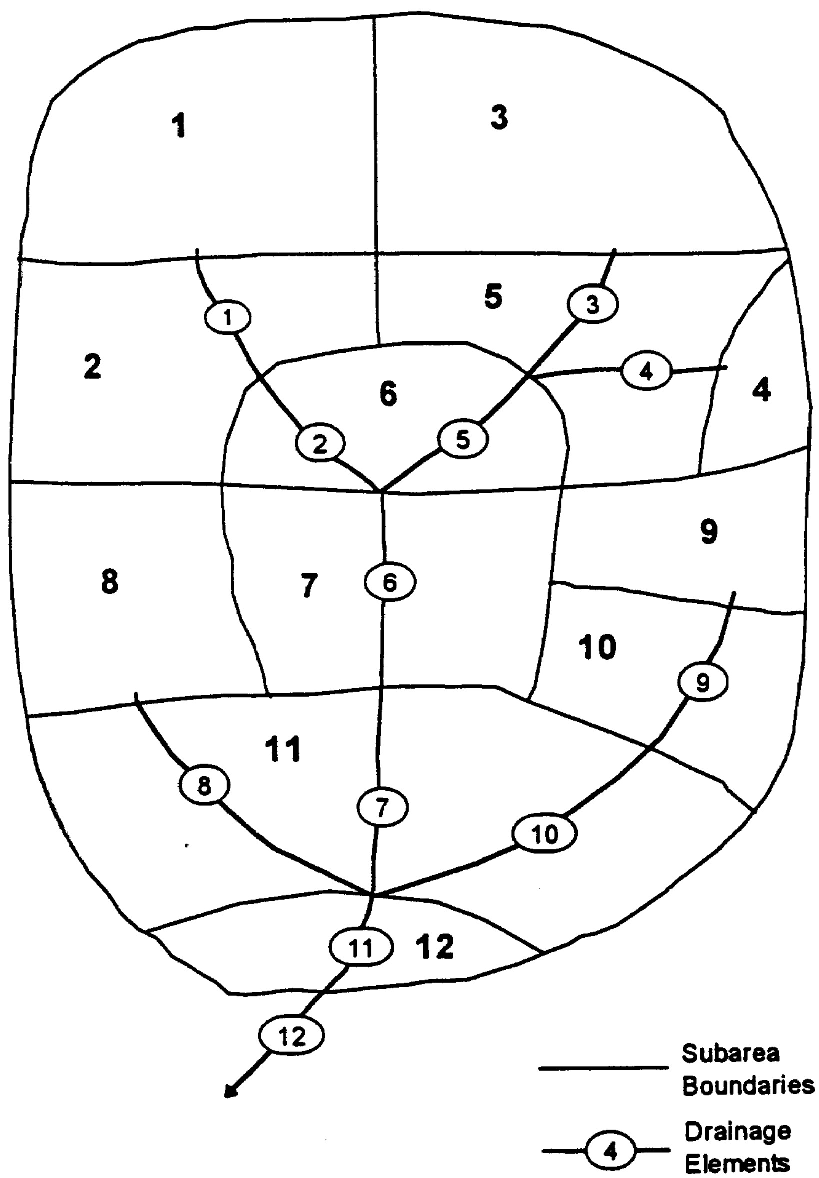


Figure 3.1 Typical watershed subdivision

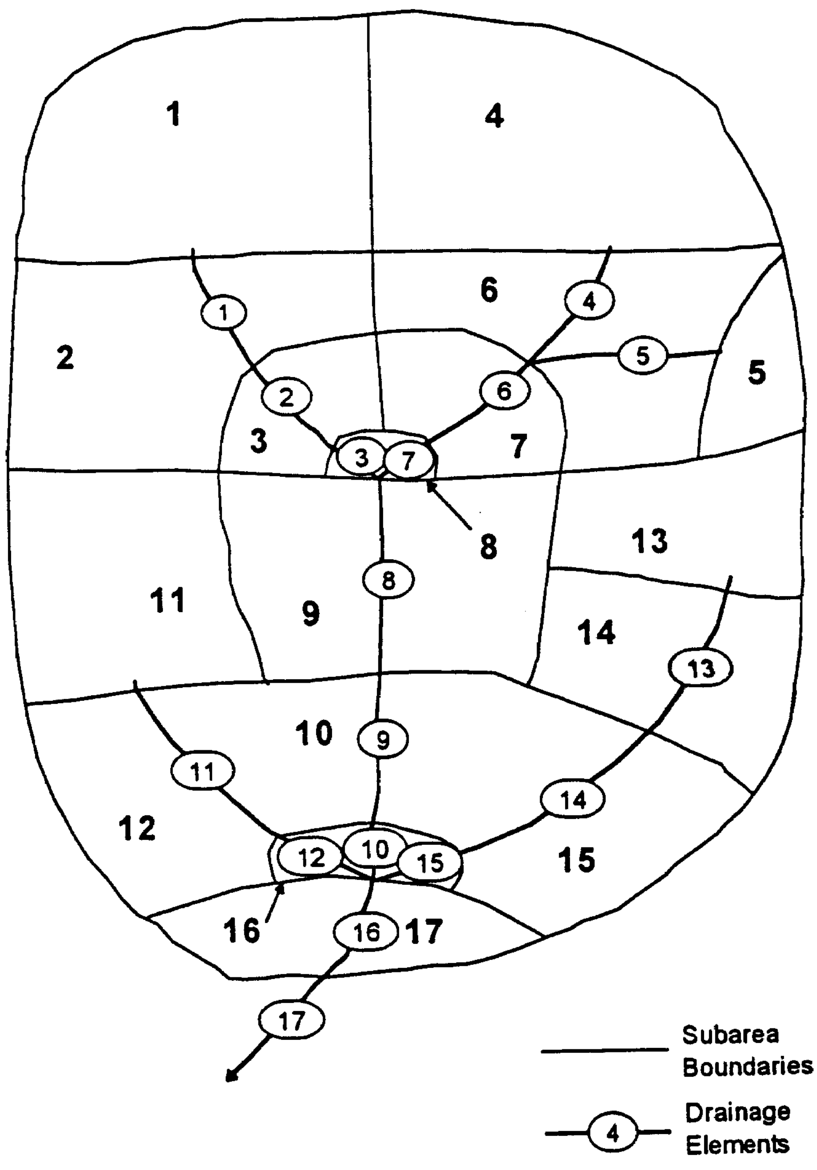


Figure 3.2 Alternate watershed subdivision

The subdivision scheme shown in Figure 3.1 has occasionally been found to contain abnormally elongated subareas, such as area 11, which the modeler may wish to subdivide in such a way that each new subarea contains only one inflowing drainage element. Such a subdivision would also be more in line with the procedures used in the program HEC-1 [U.S. Army Corps of Engineers, 1973]. In order to allow the program to proceed with the modeling process in a unified form, a small junction subarea is added at the confluence, as shown in Figure 3.2. This has the disadvantage, of course, of requiring a larger number of subareas. These junction areas, like subareas 8 and 16 in Figure 3.2, may be made arbitrarily small, a minimum of 0.01 acres.

3.2 Timing Parameters

The model requires several rainfall and runoff timing parameters. The smallest time interval in the runoff routines is the kinematic wave routing time interval, KWTI (minutes). For a good approximation of continuous kinematic wave routing, KWTI should be no larger than one-fourth of the time of concentration for the smallest subarea overland flow path encountered in the watershed. Time of concentration is defined here as the hydraulically longest flow path (largest flow time) for surface runoff to the outlet of the subarea. Of course, junction subareas such as those defined by subareas 8 and 16 in Figure 3.2 would not be included in this analysis. Note that decreasing the length of KWTI improves the accuracy of the kinematic wave routing routine, but it also requires more computation time to reach the solution.

The hydrograph time interval, HYDTI (minutes), is the time interval for each runoff ordinate in the computed hydrograph. Each HYDTI will be created by the execution of HYDTI/KWTI time intervals. Therefore, the ratio of HYDTI to KWTI must be an integer value. The data entry routine, Option 1 of the Main Menu, will not allow the entry of anything but an integer multiple of KWTI for HYDTI. This ratio of HYDTI to KWTI should not be excessively large, yet a number less than two would obviously be counter productive. As a starting point, this ratio should be between 3 and 10. After experience is gained in running the model through calibration, the user should be able to optimize on this number for a given watershed. HYDTI is also the printing interval for the hydrograph in the model output. It should also be noted that at this time, HYDTI is entered as a constant value for all storm events. Future versions of PSRM-QUAL may relax this restriction.

The rainfall time interval, **RFTI** (minutes), is the time length for each rainfall ordinate in the storm. At this time, the program requires that **RFTI** equal **HYDTI**. In the data file creation routine, the value of **RFTI** is not available for user input, and the value of **HYDTI** is used for **RFTI**. Future versions of PSRM-QUAL may relax this restriction.

If multiple storms are to be used in the model, the user must enter an inter-event time interval, **IETI** (minutes). The inter-event time interval is the time length for each inter-event ordinate during which soil saturation computations continue. Runoff and pollutant build-up calculations also continue during this period if appropriate. **IETI** is provided to the user in order to improve computation speed through inter-event periods which are typically longer than hydrograph runoff periods. It is assumed that **IETI** will be much larger than **HYDTI** and therefore, **IETI** must be an integral multiple of **HYDTI**. The data entry routine, Option 1 of the Main Menu, will not allow the entry of anything but an integer multiple of **HYDTI** for **IETI**. Presently, the model allows the entry of up to eight consecutive storms. **However,** the user should be cautioned. It is possible with a large watershed of many subareas that running eight consecutive storms could cause the computer to run out of memory.

In order for the program to completely define the time line for a single or complex storm, the user must enter the number of hydrograph points **HYDNPT** and inter-event points **IENPT** (if appropriate) for each storm. Once these parameters area entered, the program will calculate hydrograph lengths, inter-event lengths, storm start times and whatever else it may need to keep track of computed quantities and timed events associated with the storm.

In the original version of PSRM-QUAL, the user input included the timing parameters of hydrograph time length (TR) in minutes, hydrograph print interval (PRI) in minutes, routing time step (DT) in minutes, rainfall time interval (DTR) in minutes, time interval between storms (TBI) in hours, and starting time of each storm (STT) in hours. If the user was not careful, it was possible to enter conflicting information in the data file. Hydrograph lengths could actually overlap into defined inter-event periods, among other things. Therefore, the timing parameters were changed to eliminate the chance for entering redundant information. Also all input timing parameters are now in the units of minutes.

3.3 Quantity Routines

The quantity modeling process in the Penn State Runoff Quality Model contains seven major elements as listed in Table 3.1.

Table 3.1 Summary of the major runoff quantity elements in PSRM-QUAL.

Major PSRM-QUAL Runoff Elements
1. Hyetograph preparation
2. Loss estimation
3. Overland runoff computations
4. Stream and pipe flow routing
5. Reservoir and BMP routing
6. Observed hydrograph and lateral inflow addition
7. Multiple storm considerations

3.4 Hyetograph Creation Routine

Prior to any runoff calculations, the program determines the time distribution of the rainfall, otherwise known as the storm hyetograph. The method of determining the hyetograph depends on the storm option (STOPT) defined by the user in the watershed elements data block of the input file (See Chapter 6). If the user specifies observed rainfall with two or more rain gages, then the program executes a rainfall weighting routine to determine the weighted rainfall distribution for the event. If the user specifies a synthetic storm, then the program creates the design storm using a central peaking algorithm.

3.4.1 Rainfall Weighting

A rainfall weighting procedure must be applied if the rain falling on any subarea is to be estimated from data collected at two or more nearby rain gages. The coordinates of the rain gages (**XRG** and **YRG**) and subarea centroids (**XCG** and **YCG**) must be entered as input. The program computes weighting factors inversely related to the distances between rain gages and subarea centroids according to

$$WT_{ij} = \frac{d_{ij}^{-m}}{\sum_{j=1}^{n} d_{ij}^{-m}} \qquad [3.1]$$

where: WT_{ij} = weighting factor of gage j and subarea i

d_{ij} = distance between gages j and the centroid of subarea i, in a any units measured from a map.

m = inverse distance exponent. A value of m=2 is recommended by Dean and Snyder [1977].

When **STOPT** is set equal to 0 in the input file creation routine, the user will be required to enter the rainfall parameters of **NRG** (number of recording gages), **NNRG** (number of non-recording gages), **NWG** (number of gages to be used in the weighting of rainfall for each subarea, and **EXW** (exponent for weighting). For each recording gage, the user must enter **RGNAME$**, (rain gage name), **XRG** and **YRG** (rain gage coordinates), **RFNPT** (rainfall number of points), **RGST** (rain gage start time) and the sequential amounts of observed rainfall (inches). For each non-recording (total rainfall) rain gage, the user must enter **RGNAME$**, (rain gage name), **XRG** and **YRG** (rain gage coordinates) and **RFDPTH** (rainfall total depth).

For each subarea runoff calculation, the weighting routine is used to compute the rainfall distribution for that subarea. The routine searches the coordinates of all *recording* rainfall gages and identifies the recording gage which is closest to the centroid of the subarea. The routine then picks the next closest NWG – 1 rain gages (recording or non-recording) and adds them to the weighting procedure. Of course, if only one recording gage is input with no non-recording gage data, the weighting routine is not needed and therefore, not called.

The traditional way in which weighting factors have been applied to hyetographs from several rain gages often can lead to an unrealistic attenuation of the weighted hydrograph. In the example shown in Figure 3.3, a traveling storm of short duration was recorded at three neighboring gages for which weighting factors of 0.5, 0.3, and 0.2 have been established. Under traditional weighting, the rainfall increments recorded during each time interval are weighted individually, resulting in a weighted storm of long duration and low intensity as shown in Figure 3.3(d). This result is different from any one of the recorded storms.

In PSRM-QUAL, the total depth and the temporal center of gravity of the storms are computed for each rain gage. To develop a design storm for each subarea, the pattern of the hyetograph from the closest recording gage is adopted. By applying the weighting factors, the total storm depth and storm center of gravity are adjusted. The result is an upward or downward scaling and a time shift of the hyetograph while the original shape is maintained, as illustrated in Figure 3.3(e).

3.4.2 Synthetic Storms

PSRM-QUAL offers three synthetic storm options, namely the Penn-DOT design rainfall charts (PDT-IDF), the Soil Conservation Service scaled 24 hour rainfall distributions (SCS), and the U.S. Weather Bureau intensity-duration-frequency curves (USWB), also known as the Yarnell equations. All synthetic storm options require a small amount of input by the user. The synthetic rainfall routine creates central peaking storms of the duration and time step defined by the input parameters of RFTI and RFNPT. A complete description of the methodology used to compute the central peaking storm for the synthetic rainfall options can be found in the rainfall field manual by Aron, et al. [1986].

All synthetic storms can be used in a multiple storm mode, even though it may violate the statistical concept of return period. For instance, if three 10 year events were to occur back to back on a watershed, statistically speaking these three events would no longer be 10 year events. They would reduce to something more frequent, due to the increase in occurrences. However, this option is still provided.

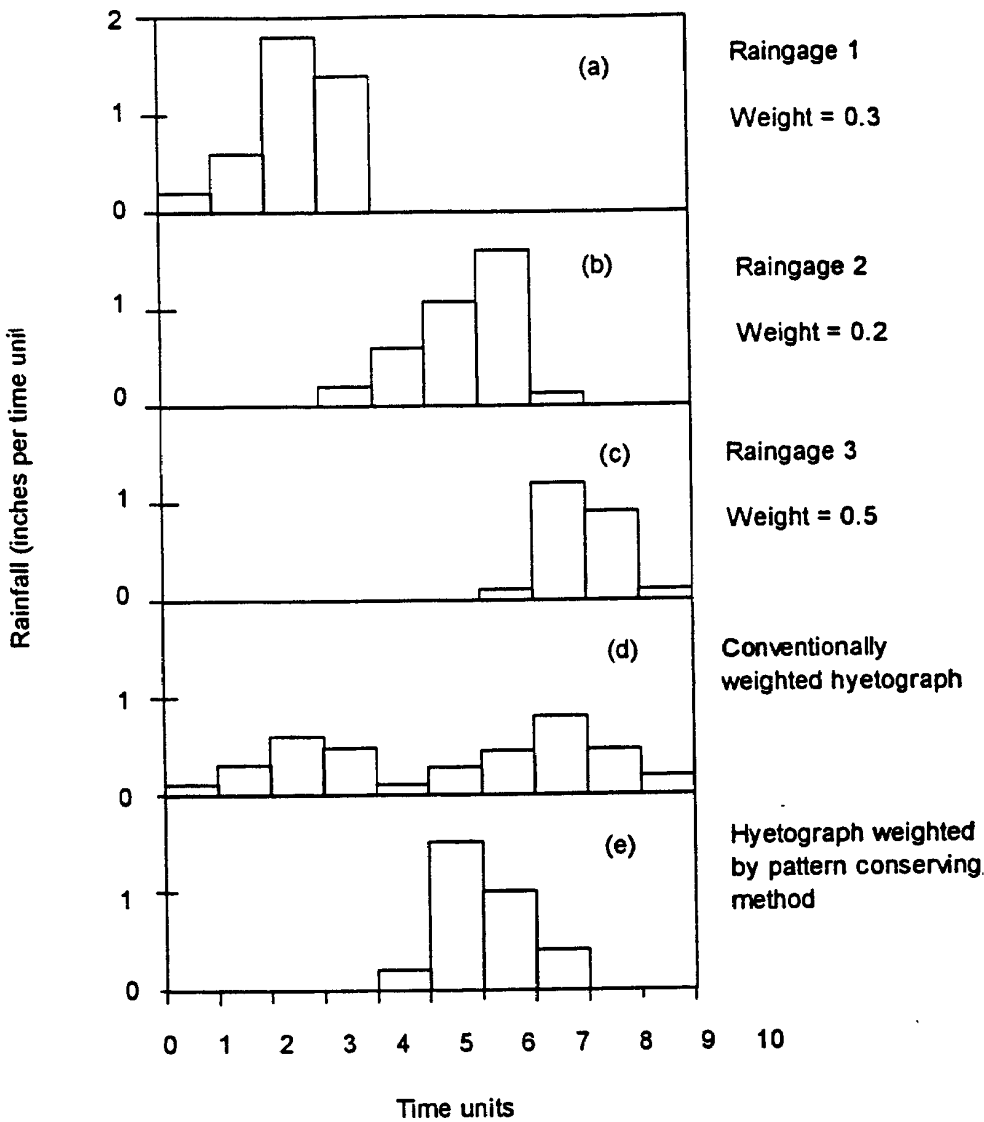


Figure 3.3 Example of PSRM-QUAL's hyetograph weighting scheme [Aron and Lakatos, 1990]

3.4.2.1 PDT-IDF Storms: STOPT 1

This option utilizes the information found in the PennDOT field manual created by Aron, et al. [1986]. This rainfall data is Pennsylvania specific, but can also be applied to areas in close proximity to the Pennsylvania borders. The user must enter REGION (rainfall region number, 1 to 5) for the watershed. Then for every storm, the user enters RETPRD (return period) and RFNPT (rainfall number of points).

3.4.2.2 SCS Storms: STOPT 2

In this option, the 24 hour rainfall distributions defined by the Soil Conservation Service [1986] are scaled to the duration specified by the user. Type I, II and III storms are available. The routine extracts the most intense storm portion of duration RFTI × RFNPT, divided into RFTI intervals. The use must also enter RFDIST (rainfall distribution type, 1, 2 or 3) and RFDPTH (24 hour rainfall depth).

3.4.2.3 USWB Storms: STOPT 3

As a third option, the intensity-duration-frequency curves developed by Yarnell [1935] for the U. S. Weather Bureau are also made available. These curves only require the input of RFDPTH (one hour rainfall depth for the storm of interest) and the storm duration through RFTI and RFNPT.

3.5 Losses

Interception losses are considered included in the SCS initial abstraction, whereas depression storage is one of the variables entered by the user. Initial abstraction and available depression storage must be satisfied before any runoff can take place. Several losses may be considered in order to obtain the rainfall excess of a storm. Some minor losses such as evaporation and transpiration may be considered negligible for simplicity since typical computational equations contain many variables and since the time intervals are relatively short. PSRM-QUAL considers only the major losses of infiltration and depression storage.

3.5.1 Infiltration

The infiltration algorithm used in PSRM-QUAL is based on a combination of Soil Conservation Service (SCS) [1972] and Horton [1935] concepts. The SCS concept is based on the runoff curve number, CN, quantified by SCS as a function of soil type and land use. The curve number is converted to a soil storage capacity, S_c, in inches, determined by the equation

$$S_c = \frac{1000}{CN} - 10 \qquad [3.2]$$

where S_c = soil storage capacity (inches).
CN = runoff curve number.

An initial abstraction representing interception and depression storage, was envisioned as a percentage of S_c or

$$IA = cS_c \qquad [3.3]$$

where: IA = initial abstraction
c = coefficient with an SCS suggested value of 0.2.

Equations 3.2 and 3.3 were used in the development of the SCS runoff equation

$$Q = \frac{(P - IA)^2}{(P - IA) + S_c}, \qquad \text{(for } P > IA\text{)} \qquad [3.4]$$

where: Q = cumulative runoff depth, inches
P = cumulative precipitation, inches

The initial abstraction term, IA, is probably the weakest link in the SCS equations. Officially, SCS recommends the relationship $IA = 0.2\ S_c$. It has been found, however, that especially for highly porous soils and smaller rainfall events, an initial abstraction of this magnitude may absorb practically all the rain and result in little or no runoff. The use of the factor c in equation 3.3 is recommended as a calibration parameter if rainfall and runoff records for an area under study are available. In the absence of data for model calibration, a value of c = 0.1 instead of the SCS factor of 0.2 is recommended [Aron and Lakatos, 1990]. The user can vary c through the initial abstraction factor parameter, **IAF**. (See the note on **IAF** in Chapter 6 under the parameter's description.)

As an alternative to equation 3.3, a fixed amount of initial abstraction may be specified by setting **IAF** to zero and entering the fixed amount as depression storage (**DS1**) for impervious areas and depression storage (**DP2**), for previous areas. This would make IA completely independent of the curve number.

In PSRM-QUAL, runoff from impervious and pervious areas are computed separately. Thus, the SCS curve number is selected separately for the impervious (**CN1**) and pervious (**CN2**) areas, whereas in other models the curve number is often weighted in proportion to the areas under various land uses.

In order to develop an infiltration algorithm, effective precipitation, P_e, is defined as

$$P_e = P - IA = P - cS_c \qquad [3.5]$$

Realizing further that infiltration plus runoff equals effective precipitation, cumulative infiltration, F, can be expressed as

$$F = P_e - Q = \frac{P_e S_c}{P_e + S_c} \qquad [3.6]$$

It must be realized that F is the soil infiltration capacity. The infiltration, as well as the runoff processes, do not necessarily take place concurrently with precipitation. Strict application of Equation 3.6 forces infiltration to take place at a high rate during a very intense rainfall burst, then to stop completely as soon as rainfall stops. The terms of maximum and equilibrium infiltration rates were adopted therefore from the Horton equation

$$f = f_c + (f_o - f_c)e^{-kt} \qquad [3.7]$$

where: f = infiltration capacity, in/hr

f_c = equilibrium infiltration rate eventually reached as the infiltration process continues and the soil becomes saturated, in/hr

f_o = maximum infiltration rate, in/hr

k = infiltration rate decrease coefficient, minutes^{-1}

t = time, minutes

The Horton equation in itself is not used in PSRM-QUAL, but values for f_c and f_o compiled by Rawls et al. [1983] and shown in Table 3.2, were adopted. Here, f_c is assumed to be equivalent to saturated hydraulic conductivity, K_s. For a particular soil f_c must be chosen by the user input through the parameter KS. The program then computes the maximum infiltration rate as

$$f_o = 0.037 + 1.84 f_c - 0.075 f_c^2 \qquad [3.8]$$

Table 3.2 Average values of saturated hydraulic conductivity [Rawls, et al., 1983]

Soil Texture Class	K_s, in/hr
Sand	4.64
Loamy sand	1.18
Sandy loam	0.429
Loam	0.134
Silt loam	0.256
Sandy clay loam	0.0591
Clay loam	0.0394
Silty clay loam	0.0394
Sandy clay	0.0236
Silty clay	0.0197
Clay	0.0118

Note: The saturated hydraulic conductivity, K_s, is considered equal to the equilibrium infiltration capacity, f_c.

The program uses equation 3.6 to compute available cumulative infiltration capacity, but limits the infiltration rate by the equation

$$f = f_o - (f_o - f_c)\frac{CF}{S_c} \qquad [3.9]$$

where CF is the accumulated water in the soil, at any time during or after a storm burst. Since the program allows the modeling of sequential storm bursts interrupted by rainless periods, allowance was made for the depletion of CF by a deep percolation function, d, defined as

$$d = f_c \frac{CF}{S_c} \qquad [3.10]$$

and CF was adjusted in each time step as

$$CF = \Sigma(f - d)\Delta t \qquad [3.11]$$

The same recovery was allowed for the available infiltration capacity F in equation 3.6 so that an updated capacity

$$F = \frac{P_e S_c}{P_e + S_c} + \Sigma d \Delta t \qquad [3.12]$$

is computed at each time step to put an upper limit on the infiltration rate computed by equation 3.9. The infiltration and deep percolation process is illustrated in Figures 3.4 and 3.5.

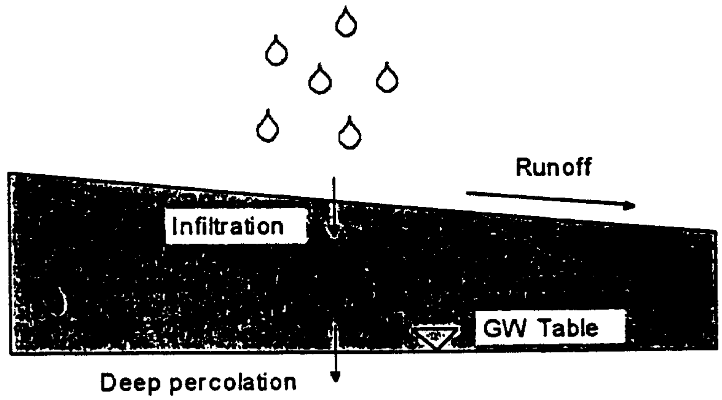


Figure 3.4 Infiltration and deep percolation schematic

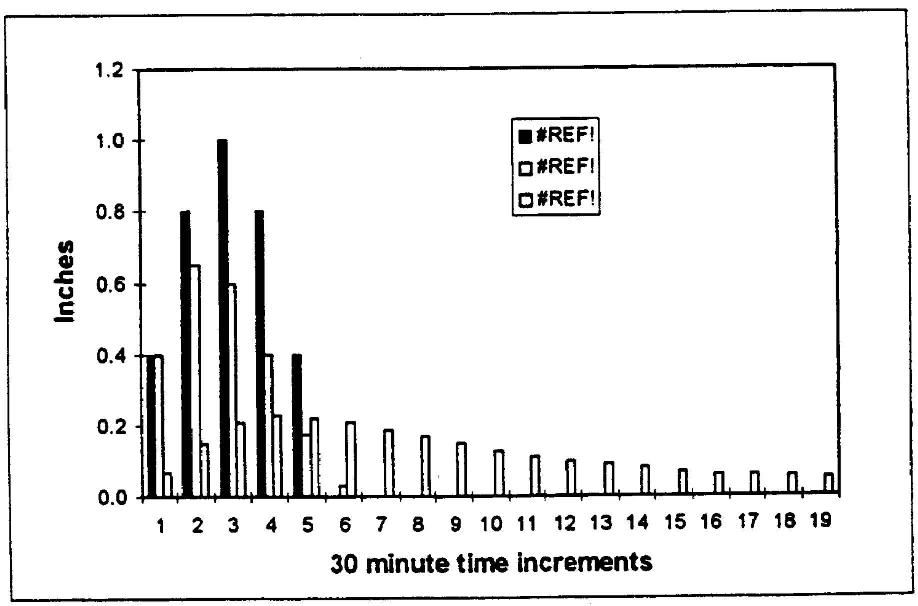


Figure 3.5 Infiltration and deep percolation for a storm with completely unsaturated initial conditions

The user is asked to enter the initial ratio CF_o/S_c of soil water capacity filled as input parameter **IFSW** (initial fraction of the soil wetted), which depends on the time since the most recent storm event. This parameter typically has a value between 0 and 0.5. From then on CF is continuously updated as

$$CF = CF_o + \Sigma(f - c)\Delta t \qquad [3.13]$$

3.5.2 Depression Storage

In many models, including previous versions of the Penn State Runoff Model, depression storage is considered as a separate loss. This gives the user flexibility in considering all losses.

Depression storage for a given location may be a constant, or a function of the land use. For the input variable depression storage, the user must enter a value for the impervious (**DS1**) and the pervious (**DS2**) areas. This value may also include other minor losses which the user feels must be considered and are better represented by a constant depth.

Alternatively, the user may adjust the initial abstraction term, **IAF**. Initial abstraction is defined as the losses due to interception, detention, and depression storage. Thus the user has the ability to enter depression storage into the initial abstraction as a fraction of the soil storage capacity. Since initial abstraction is a function of land use, differences between impervious and pervious areas have already been taken into account. As with the constant depression storage term, other losses may be handled by adjusting the value of **IAF** (c in equation 3.3).

3.6 Overland Runoff

Overland runoff is a shallow flow process in which rainfall accumulates on the land until the buildup water sheet is thick enough to cause runoff. The flow problem is usually solved by the kinematic wave method [Kibler, 1968], which is based on the principles of conservation of mass and momentum. The process is illustrated in Figure 3.6, in which the water surface profile has built itself up to an equilibrium condition. In this state the difference of outflow and inflow rates equals the rainfall rate on a section of length dx.

Symbols used in Figure 3.6 and the following runoff equations 3.14 through 3.21 include:

A = cross-sectional flow area, ft^2
F_x = summation of forces in the x-direction acting on the control volume
g = gravitational constant
γ = specific weight of water, 62.4 pcf

h = local depth, ft
i = lateral inflow or rain excess rate, cfs per foot of length
M = mass of water contained in the control volume
m_l = mass of lateral inflow

n = manning roughness
η = exponent defining flow regime (assumed turbulent, 5/3)
q = discharge per unit width, cfs/ft
S_o = slope of plane or channel, ft/ft

S_f = friction slope, ft/ft
t = time, seconds
u = lateral inflow velocity, fps, in x-direction
v = local velocity, fps

x = distance downstream, ft
y = depth of flow, ft

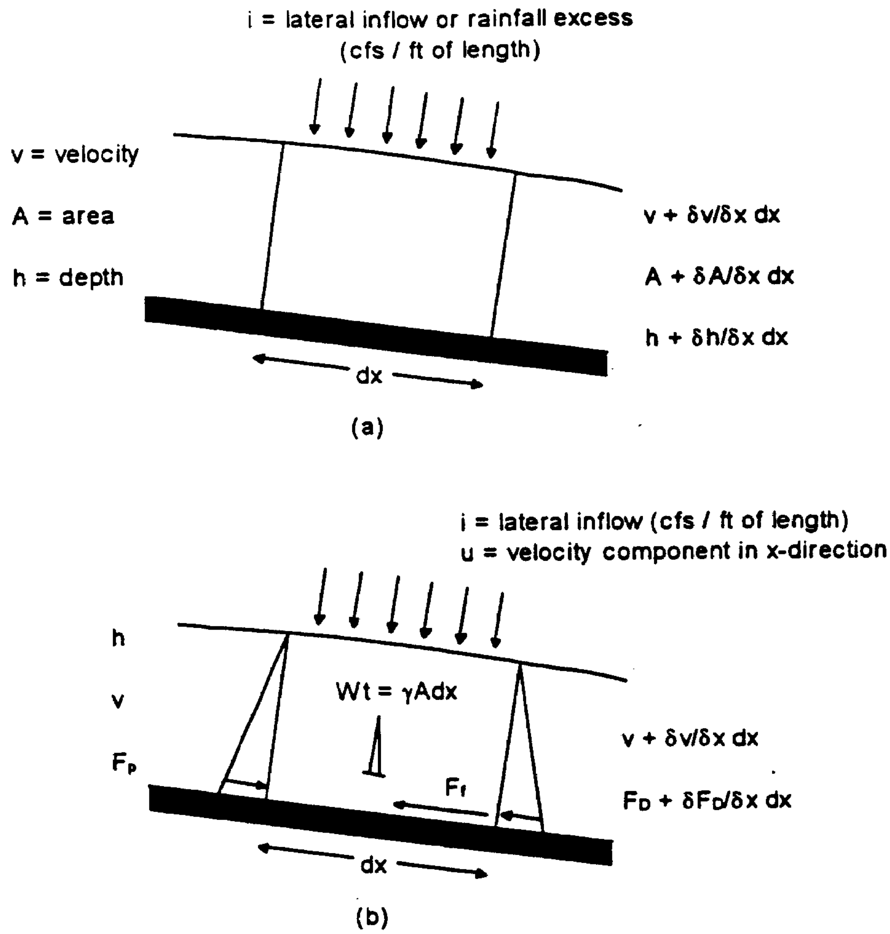


Figure 3.6 Overland runoff schematics: (a) Conservation of mass, (b) conservation of momentum

The basic equations for the kinematic wave process are the following:

Conservation of Mass:

$$\left(Av + i\ dx\right)dt - \left(A + \frac{\partial A}{\partial x}dx\right)\left(v + \frac{\partial v}{\partial x}dx\right)dt = \frac{\partial A}{\partial t}dt\ dx \qquad [3.14]$$

inflow - outflow = Δ storage

Conservation of Momentum:

$$F_x = M\frac{dv}{dt} + m_1\frac{du}{dt} = \gamma AS_o dx - \gamma AS_f dx - \gamma A\frac{\partial h}{\partial x}dx \qquad [3.15$$

momentum change = weight – friction – pressure difference

Equations 3.16 and 3.17, derived from equations 3.14 and 3.15, form the basis of the kinematic wave model for overland flow. The system of equations in 3.16 and 3.17 are first order, nonlinear partial differential equations. These can be transformed to a set of ordinary differential equations by the characteristic method.

$$\frac{\partial y}{\partial t} + \alpha\eta y^{\eta-1}\frac{\partial y}{\partial x} = i \qquad [3.16]$$

$$\frac{\partial y}{\partial t}dt + \frac{\partial y}{\partial x}dx = dy \qquad [3.17]$$

Equations 3.16 and 3.17 can be solved analytically by the method of characteristics, leading to equations 3.18 to 3.21.

$$y_1 = y_o + i(t_1 - t_o) \qquad [3.18]$$

$$x_1 - x_o = \frac{\alpha}{i}\left\{\left[y_o + i(t_1 - t_o)\right]^\eta - y_o^\eta\right\} \qquad [3.19]$$

$$t_1 - t_o = \frac{1}{i}\left\{\left[(x_1 - x_o)\frac{i}{\alpha} + y_o\right]^{1/\eta} - y_o\right\} \qquad [3.20]$$

$$q = \alpha y^\eta \qquad [3.21]$$

This set of equations was originally used in the program to compute runoff from a subarea. It was found, however, that this approach did not lend itself favorably to the simulation of sediment transport. After each time step, the sediment remaining on the land had to be redistributed uniformly over the entire subarea. A modification was therefore made solving equations 3.16 and 3.17 numerically through overland sub-strips of length, Δx, (Figure 3.6) by cascading the runoff from sub-strip to sub-strip. The outflow from one sub-strip becomes the inflow to the next one immediately downhill. This practical numerical procedure could be adapted well to the sediment transport routine.

The overland flow width, W, is the width over which the runoff approaches the main drainage element(s) in a subarea. This width is defined by the program as the ratio of sub-basin area (**AREA**) to a characteristic overland flow path length (**LENG**). The user should carefully consider each sub-basin geometry before establishing the value of **LENG**. In the simple case where the storm sewer is located close to the centerline of the subarea as illustrated in Figure 3.7, W may be taken as twice the drainage element length, Ls. For the more general case in which the overland flow approaches one or more drainage elements within a subarea in a less than symmetrical pattern, a "typical" overland path length, **LENG**, must be chosen, keeping in mind that W is computed as **AREA** divided by **LENG**.

The overland flow rates are computed for a unit width separately for the impervious and pervious portions of the subarea. They are then multiplied by the appropriate overland width and combined to create the hydrograph.

3.6.1 Sinuosity Factor

For the overland flow path, the flow length, **LENG**, is usually measured as a straight line on a map. Subsequently, the overland path slope, **SLOPE**, is typically computed as the ratio between the elevation differential and length. In reality, the overland flow path is most likely undulating. For each subarea, a sinuosity factor, **SF**, can be entered to increase the measured path lengths. The program will multiply the specified overland flow length and divide the flow slope by this factor for the subareas.

3.7 Stream/Pipe Flow

PSRM-QUAL treats storm drainage elements and not storm sewers as such. The reason for this is that the drainage from small areas may be concentrated in channels as well as in storm drains. Routing through these elements is accomplished using the Muskingum method.

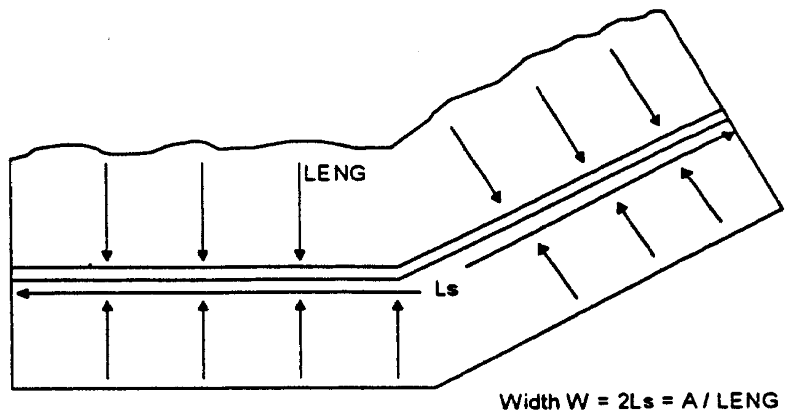


Figure 3.7 Subarea example indicating width of overland flow.

The five input parameters for drainage elements are:

1. **CAP**, the full flow capacity in cfs, which can be determined for any given size, shape and slope of pipe or channel by using the Manning's equation or design charts;
2. **PT**, the travel time of the drainage element in minutes, which can be estimated as the drainage element length divided by it's full flow velocity;
3. **MX**, the drainage element Muskingum weighting factor (referred to as the "X" coefficient) which varies between 0 and 0.5;
4. **CTS**, the ratio of the channel to surface (or pipe to gutter) flow travel times for surcharge modeling. Values of **CTS** can vary from 1.5 to 4.0 for channel to overbank travel times, depending on the relative stream bed and overbank roughness. For pipe to gutter ratios, **CTS** can vary from about 1.5 to 2.0. **CTS** can be a highly effective calibration parameter;
5. **NCDE**, the number of connecting drainage elements. This number can be any value between 0 and 3. The user will be required to enter a drainage element ID number for each connecting drainage element.

The numbering of drainage elements must be sequential, in a downstream order, as shown in Figure 3.1. Drainage elements are numbered starting from the upper end of any one of the branches and continued down to the first junction, at which point another branch is picked up, and so forth until all branches above the junction have numbered reaches. The reaches below the junction are then numbered sequentially until another branch joins the drainage system, at which point the numbering sequence once again starts at one of the upper extremes of the incoming branch. This numbering process continues until the outflow element of the watershed is reached. If the watershed outflow spills into a stream or swale of essentially unlimited capacity, an arbitrarily chosen large flow capacity should be specified to let the program know that there will be no backwater effects on the watershed drainage system. Since the last drainage element In the system is used only for surcharge calculations of the upstream subarea, the channel routing travel time of this element is immaterial . Nevertheless, a travel time for this drainage element must be entered in the data file for the program to operate.

Each subarea drainage inlet directs flow to one pipe (or element) which will drain the subarea. No more than one element can leave any drainage inlet. The drainage inlet, on the other hand, can accept flow from up to three incoming elements. Figure 3.8 illustrates the conceptual structure of a drainage inlet.

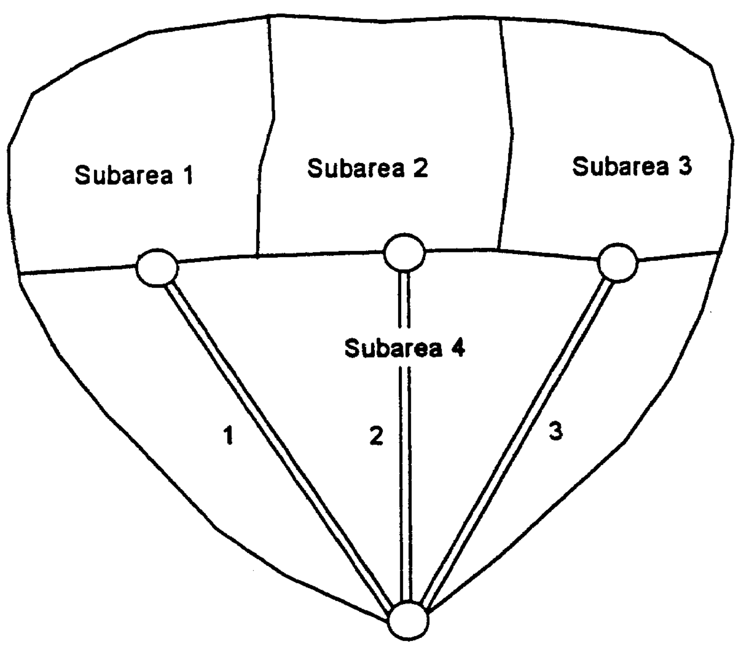


Figure 3.8 Conceptual structure of a drainage element [Aron and Lakatos, 1990]

3.7.1 Routing through Channels

The travel time of runoff in drainage elements may be computed by various techniques. The Muskingum Method, used in this model, is a straightforward method which considers storage within the reach.

Storage in a reach depends primarily upon the discharge into and out of that reach and upon the hydraulic characteristics of the channel. Assumptions by the Muskingum method [Viessman et al., 1977] produce equation 3.22 for storage.

$$S = K_m\left[X_m I + (1 - X_m)O\right] \quad [3.22]$$

where:
- K_m = storage time constant for the reach.
- X_m = weighting factor which varies between 0 and 0.5 for a given tributary section.
- I = inflow rate to the reach, cfs.
- O = outflow rate from the reach, cfs.
- S = storage within the reach, cuft.

The value for the storage time constant, K_m is assumed to be equal to the travel time within the reach. This term may not be greater than three times the time interval of the inflow if numerical stability of the routing method is to be maintained. To remedy such a problem, the model automatically subdivides the reach into as many sub-reaches as necessary and routes the hydrograph through each sub-reach, effectively reducing the value of K_m for each sub-reach.

The weighting factor, X_m, defines the amount of translation (time lag) and the amount of attenuation (reduction in peak discharge) of the downstream outflow. A weighting factor of 0.5 produces a pure translation of the inflow hydrograph with no attenuation. Such a situation may occur in flow through a pipe. A weighting factor of zero, on the other hand, produces a reduced translation and maximum attenuation. Figure 3.9 indicates the effect of the chosen weighting factors on an outflow hydrograph. A natural stream channel typically has an intermediate weighting factor of 0.2 to 0.3.

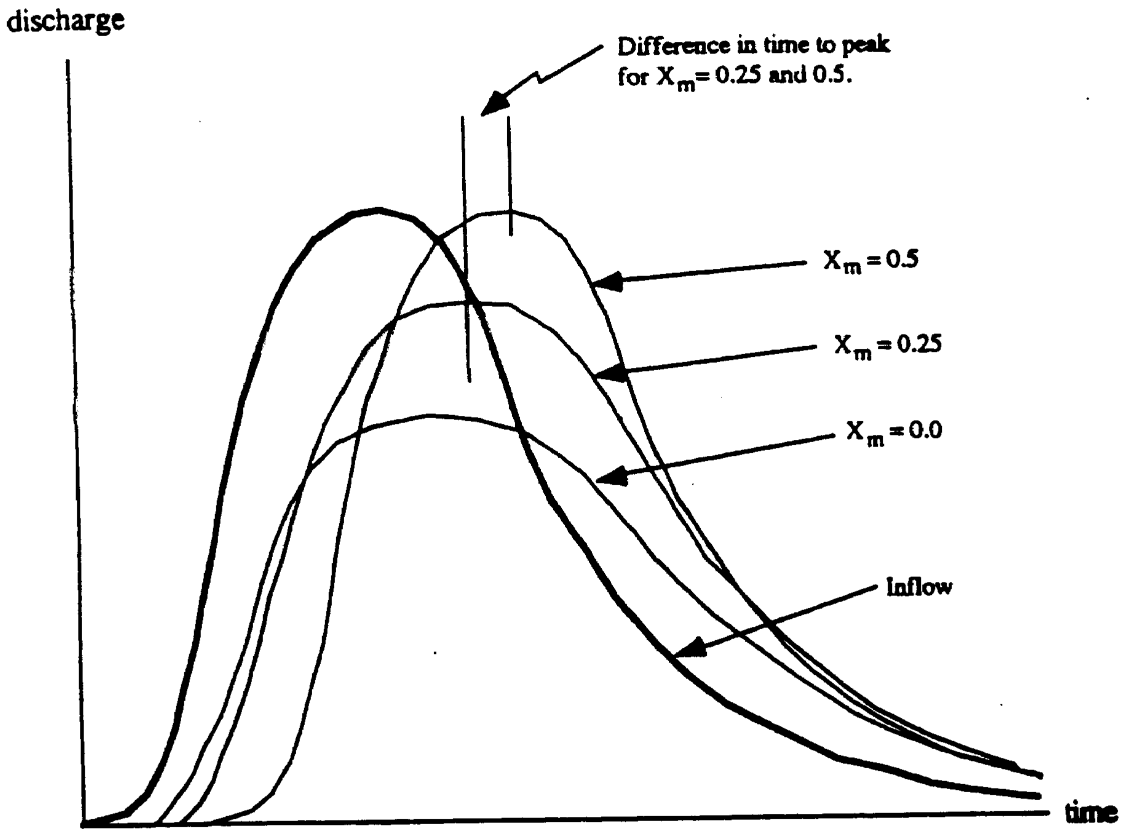


Figure 3.9 Muskingum routing with extreme and medium weighting factors.

3.7.2 Surcharging

Surcharge is assumed to occur, for modeling purposes, when the capacity of any drainage element, CAP, is exceeded. When surcharging occurs, flow is assumed to leave the storm drainage system. The surcharge flow travels overland to the next downstream inlet where it again attempts to be accepted by that inlet as sewer flow. The travel time of surcharge flow is assumed to be equal to that of the corresponding storm sewer, PT, multiplied by the coefficient CTS described earlier in this section. The value of CTS should be determined by the modeler on the basis of general hydraulic engineering judgment.

At the end of printed hydrograph output for the complete watershed, a list of all surcharging subareas is provided. Surcharge subareas are defined as those areas in which the surcharge flow rate exceeds the drainage element capacity by a specified percentage. This percentage is currently set in the model code as 10%.

3.8 Routing through Reservoirs and BMPs

If a reservoir or BMP exists in a subarea, then the reservoir routing routine is called. This routine can be performed for a maximum of one reservoir per subarea. The input data required for the reservoir routing routine include corresponding water surface elevation (ft), storage (acre-feet), and outflow (cfs) data sets. A maximum of 12 elevation-storage-outflow ordinates may be entered for each reservoir.

The method used for reservoir routing is adapted from a hydrologic river routing method founded on the equation of continuity:

$$I - O = \frac{dS}{dt} \qquad [3.23]$$

where:
- I = inflow rate, cfs.
- O = outflow rate, cfs.
- $\frac{dS}{dt}$ = rate of storage change, cfs.

To apply this to a reservoir routing, equation 3.23 is modified for short time steps, Δt, resulting in equation 3.24

$$(I_n + I_{n+1}) + \left(\frac{2S_n}{\Delta t} - O_n\right) = \left(\frac{2S_{n+1}}{\Delta t} + O_{n+1}\right) \qquad [3.24]$$

where:
- I = inflow rate, cfs.
- O = outflow rate, cfs.
- S = reservoir storage, cuft.
- Δt = time increment, seconds.

This method is known as the storage indication or Modified Puls method [Viessman et al., 1977]. For a given time step, all quantities on the left side of equation 3.24 are known. The right side quantities are unknown, but the value of $2S/\Delta t + O$ can be computed. A storage-outflow table provided by the user is used to develop a $2S/\Delta t + O$ versus O curve that is used to solve for outflow, O, at the end of the time step.

During the routing of inter-event runoff (if present), the routing routine redefines the inter-event runoff in intervals of HYDTI by interpolation. This is necessary such that the same storage indication relation established for the hydrograph segment of the storm can be used to solve for outflows of the inter-event segment. This storage relation is dependent on HYDTI and cannot be used for other time intervals.

3.8.1 Reservoir Types

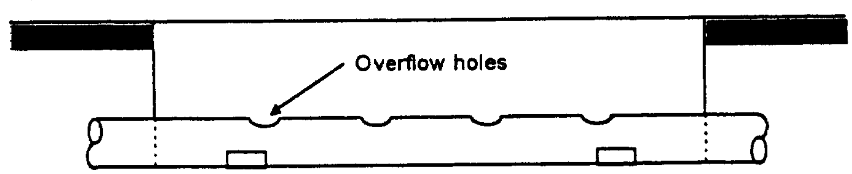
Two reservoir types, RTYP, can be considered. Type 1 is used to accommodate the overland flow contribution from the subarea on which it is located. The hydrograph from this source is first attenuated by the reservoir and then returned to the hypothetical inlet structure at the lower end of the subarea, where it combines with the pipe flow from upstream areas to become "the sum of the subarea outflows at a given junction."

A Type 2 reservoir is located at the subarea outlet and will allow the "sum of subarea outflows at a given junction" to be diverted and attenuated, whether this outflow consists of pipe or surcharge flow. This type of reservoir, naturally, is much more effective than the first in diverting a large flood volume. However, unless this reservoir is of substantial size, it may easily fill up with the first flush and overflow by the time the flood peak arrives. To remedy the situation, a reservoir bypass flow rate, QBYP, can be defined for each reservoir, representing the flow rate which will travel through or around the reservoir.

3.8.2 Flow Bypass in Reservoirs

Bypass flow is defined simply as that flow which is not routed through the reservoir. Specifying QBYP = 60, for example, allows the outflow to proceed down the storm sewer until it reaches 60 cfs, at which time the excess will begin to enter into the reservoir. This bypass option is highly effective in cutting the size of the reservoir needed for a particular desired reduction in flood peak. However, if runoff quality concerns are more important than flooding concerns, this option should not be used.

In practice, a reservoir bypass can be achieved by installing a storm sewer above the bottom of a retention pond and providing the sewer with holes along its top. The holes allow storm water to spill into the pond when the desired bypass capacity is exceeded. To drain the pond after the recession of the flood, either one-way flap gates may be installed downstream along the sewer bottom or a small diameter pipe may be laid from the pond to a downstream inlet at which the pond drainage can rejoin the storm sewer by gravity flow as shown in Figure 3.10.



Section AA

Figure 3.10 Schematic of detention facility low-flow bypass structure.

3.9 Observed Hydrographs and Lateral Inflow

Wherever recorded or observed hydrographs are available at one or more stations they may be entered as input and will be printed alongside the simulated hydrographs for comparison. This is an observed hydrograph of **HTYP** = 0.

The observed hydrograph input option may also be used to designate a lateral inflow hydrograph, **HTYP** = 1, namely an inflow from some source outside the watershed. This could represent a tributary with a separately computed outflow hydrograph, a storm sewer contribution form an outside source, or a diversion of water out of the watershed, in which case the inflow hydrograph would have negative ordinates. Another situation in which the specification of an inflow hydrograph could be useful is one in which the modeling process has to be interrupted, possibly because the number of subareas becomes excessively large. In this case, the modeled outflow from the lowest subarea can be entered as an inflow hydrograph of the watershed extension and the modeling continues from that point.

3.10 Multiple Storm Considerations

Several considerations must be made for multiple storm analyses. When analyzing multiple storms, the time between the storms is crucial to the infiltration of the following storm. If a 6-hour storm is repeated after 24 hours, the soil may still remain highly saturated; however, if the 6-hour storms are separated by 7 days, more deep percolation occurs and the soil will likely be nearly unsaturated. To account for this, the filled capacity of the soil is tracked throughout. The effect of multiple storm bursts on the infiltration algorithms was described in section 3.3.2.

Another result of a multiple storm analysis is the continuous hydrograph. All hydrographs for a subarea are combined into one continuous hydrograph including the time intervals between storms. Each storm hyetograph and hydrograph can still be easily distinguished in the output by observing the variation in time step duration.

4

DETAILS OF OVERLAND FLOW QUALITY MODELING

4.1 Non-point Source Pollution

The term "non-point source pollutant" may be defined simply as any pollutant which does not come from a specifically located and known "point" source. Therefore, any pollution whose discharge cannot be completely controlled is considered a non-point source. As an example, pollution from a sewage treatment plant is considered a point source pollutant since the source is specifically located and the discharge of pollutants can easily captured. In contrast, pavement degredation is a non-point source pollutant. It is difficult to know where the pavement is decomposing or how much degradation is occurring. The quality routines of this model attempt to quantify the fundamental processes of non-point source pollutant transport through a watershed. The routines have been identified as dry weather buildup, dislodging by rainfall and washoff by surface runoff. Each of these processes will be discussed later in this chapter.

4.2 General Approach to Overland Flow Quality Modeling

PSRM-QUAL models the pollutants of TSS, Cu, Zn, Pb, TKN, NO2+NO3, TP, SP, COD, BOD, and two user defined conservative trace organics. The fundamental assumption made in the model is that for surface runoff calculations, all modeled pollutants are directly associated to total suspended solids. Thus, the surface runoff quality routines of buildup, dislodging and washoff track only solids.

4.2.1 Pollutant Concentration Factors

The content of the data file POLC.DAT as shown in Table 4.1, contains a matrix of pollutant concentration factors varing with land use and are referenced to TSS, in units of grams of pollutant per 100 grams of TSS.

Table 4.1 Content of the data file POLC.DAT

POLC.DAT: Pollutant Factors for PSRM-QUAL

Pollutant Concentration Factors in g/100g of TSS

	Cu	Zn	Pb	TKN	NO2+3	TP	SP	COD	BOD
Residential	0.0327	0.134	0.143	1.88	0.729	0.379	0.142	72.3	9.9
Mixed	0.0403	0.230	0.170	1.93	0.833	0.393	0.084	97.0	11.6
Commercial	0.0420	0.328	0.151	1.71	0.829	0.291	0.116	82.6	13.5
Open/NonUrban	0.01	0.279	0.043	1.38	0.776	0.173	0.037	57.1	7.9

Pollutant Loading Factors

	curb-meters/hectare	build-up exponent
Residential	385	0.2
Mixed	385	0.2
Commerical	385	0.2
Open/NonUrban	385	0.2

These factors are applied directly to a TSS load to determine the associated load of other pollutants. For example, if the total sediment load in a given hydrograph ordinate was 250 grams of TSS and the subarea landuse was residential, the associated pollutant load of zinc would be

$$(250\text{g TSS}) \times (0.134 \text{ g Zn}/100 \text{ g TSS}) + 100 = 0.335 \text{ grams of zinc.}$$

Concentrations are then computed by dividing the pollutant load by the product of the associated flow rate (cfs) and time interval (minutes), then using the appropriate units conversion factors to convert grams of pollutant to milligrams per liter. Note that the file also contains data defining the amount of curb-meters per hectare of impervious area and a pollutant build-up exponent, both as a function of land use. These data are used in the sediment loading and build-up routine described later in section 4.3.

The file POLC.DAT was created to provide the user with the flexibility of adjusting the pollutant concentration factors to the observed conditions of the watershed of interest. The data presented in Table 4.1 were calculated using average values found in the NURPS data and other sources. The pollutant concentration factors in the NURPS data from one site to the next were often observed to vary one or two orders of magnitude. Because of this extreme variation in pollutant concentration factors from one site to another, the user is strongly encouraged to collect field data in the watershed and verify or adjust the content of POLC.DAT before calibrating the model. The content of POLC.DAT can be changed by using any text editor or by using MS-DOS EDIT through Option 2 in PSRM-QUAL's Main Menu. See Appendix A of this manual, "Changing the Content of DAT Files".

The first version of PSRM-QUAL used POLC factors that varied by particle size as well as land use. Laboratory investigations with respect to variation of pollutant concentration factors as a function of particle size were performed by Tai [1991] at Penn State University. Tai found that the majority of pollutants sorb to the smaller particles and that there was significant variation in the POLC factors between the very large particles to the very fine particles. The results of his work, which was consistent with data presented by Sartor and Boyd (1972) and Novotny and Chesters (1981), became the content of the original POLC file used with PSRMQ91 and is shown in Table 4.2. During the programming work performed on PSRM-QUAL to include the effects of BMPs (Chapter 5 of this manual), it was found that the pollutant concentrations generated by the old model were consistently low as compared to the quality data found in the literature (mainly NURPS data). As a result of this finding, Tai's data was removed from the POLC.DAT file and replaced with association factors found or implied in the NURPS data. It may be possible to revise the model in the future to include factor variations due to particle size.

As a result of this change in the POLC.DAT file, the priority pollutants had to be changed. In the NURPS data, there was very little information on volatile solids that would allow the estimation of a pollutant concentration factor. Plenty of data was available for fecal coliforms, but the range of reported values varied over five orders of magnitude. This data was considered unusable in a computer model. These two pollutants were dropped and replaced with soluble phosphorus and nitrates plus nitrites. These two new pollutants were relatively well documented in the NURPS data.

Table 4.2 Contents of the file POLC used in PSRMQ91 (no longer used).

Pollutant Concentrations (gram of pollutant per 100 gram of solids)

	Cu	Zn	Pb	Vol.S	BOD	COD	FCOL	TKN	TP
Impervious fraction									
Fines	0.039	0.139	0.105	46	6.0	3.25	67000	0.97	0.173
Medium	0.003	0.004	0.008	4.6	0.6	0.35	7000	0.17	0.018
Coarse	0.004	0.004	0.005	1.4	0.3	0.30	5000	0.02	0.010
Pervious fraction									
	0.003	0.005	0.001	5.0	0.4	2.5	50000	0.20	0.07
Land Use Factors									
Resid.	0.960	1.19	0.314	1.13	1.13	0.641	2.39	1.54	1.02
Indust.	0.556	0.847	0.286	.846	0.85	1.10	0.597	1.29	0.36
Comm.	1.27	1.52	0.838	1.22	1.22	0.598	0.881	1.03	0.932
Transp.	1.21	0.449	2.56	.806	0.80	1.66	0.138	0.144	0.683

4.2.2 Particle Sizes and Ranges

The surface loading of pollutant particulates are initially input by the user in the form of total load in grams per curb meter through the paramter ISL. Later, during program operation, if multiple storms are used, the buildup routine will compute a new surface loading based upon the effects of the first storm and the buildup during the inter-event period. Once the surface loading is established, the program distributes this loading into six particle size ranges. The particle size ranges and distributions are contained in the data file PSDIST.DAT which is shown in Table 4.3. The file provides the grain size limits for thirteen size ranges from 4800 microns (4.8 mm) to 0.8 microns. The "Overland Flow Distribution" places 21% of the surface loading in the size range of 4800 microns to 2000 microns. Likewise the last size range places 25% of the surface loading in the size range of 74 microns to 0.8 microns. All of the runoff quality routines deal with sediment loads in these six size ranges. This allows the program to track dislodging and washoff as a function of particle size. The total sediment load used to compute pollutant concentrations is the sum of the six size range loadings.

Three other particle size distributions are shown in PSDIST.DAT and are based on thirteen particle size ranges. These distributions are used later in the program if the effect of a BMP on solids removal is to be evaluated. The program further distributes sediments contained in the smallest size range of the original "six size"

Table 4.3 Content of the file PSDIST.DAT

```
PSDIST.DAT: Particle Size Distributions for PSRM-QUAL
 GrainSize ID Numbers for 13 groups of sediments
  0     1     2    3    4    5   6   7   8   9    10  11   12  13
 GrainSize (microns)
  4800  2000  840  250  105  74  65  55  45  35  25  15  5   0.8
 Distribution for six size groups in surface runoff modeling
      21    5    16   20   13  25
 UltraFines Distribution in BMP [74 microns and smaller]
                               41  23  15   9   6   3   2   1
 Suspended Solids Distribution in BMP
       0    0    0    0    0  0.5 0.8  1.2   1.5   2   9  25  60
 Bottom Sediments Distribution in BMP
       5    12   23   11   9   8   7   6   6   5   4   3   1
```

distribution into eight more size ranges, to improve the modeling ability of the BMP sediment removal routines. This will be discussed further in Chapter 5.

The file PSDIST.DAT was created to provide the user with the flexibility of creating particle size distributions for a given watershed application. Particle size distributions can vary significantly based on geographic location. The distribution can significantly affect the output results of the model both in the overland flow runoff routines and the BMP sediment removal routines. Users of this model are strongly encouraged to collect particle size distribution data for specific watersheds and modify the contents of PSDIST.DAT prior to calibration of the model. The content of PSDIST.DAT can be changed by using any text editor or by using MS-DOS EDIT through Option 2 in PSRM-QUAL's Main Menu. See Appendix A of this manual, "Changing the Content of DAT Files"

4.3 Pollutant Buildup

Buildup is a physically based formulation used in urban runoff quality models. The term "buildup" represents a wide range of dry weather processes including deposition, wind erosion , and street cleaning [Huber, et al., 1981]. These processes produce an accumulation of solids which can be washed off during a storm event. Note that the buildup equations used in this model apply only to the impervious portion of the watershed. Sediments in pervious areas are already in place and need only to be dislodged and washed off.

4.3.1 Sources of Buildup

Numerous sources of buildup exist; however, the sources of the majority of the urban pollutants are known. Table 4.4 summarizes the main sources of non-point source pollutant buildup. From these sources, the general constituent makeup of non-point source pollution is known. The analysis of this pollution will emphasize these constituents which include copper, lead, phosphorous, and organic materials.

Table 4.4 Summary of non-point sources of pollutant buildup, [Huber, et al., 1981]

1. Antiskid and deicing compounds
2. Atmospheric fallout
3. Automotive emissions and decay
4. Construction
5. Land surface erosion
6. Pavement degradation
7. Snow accumulation
8. Spills
9. Vegetation and leaf litter

4.3.2 Buildup Theory and Equations

Estimating the buildup of pollution is a critical element in the computation of non-point source washoff. For urban areas, pollutant buildup is typically limited to some equilibrium loading condition. It is assumed that a steady-state condition for dry weather buildup and removal processes is reached after a certain period of time. Consequently, an exponential loading of pollutants is a frequently used formulation. This formulation is used in the model and can be expressed as

$$P_R = P_{max}\left(1 - e^{-b\Delta t}\right) \quad [4.1]$$

where: P_R = surface pollutant load at the end of time interval Δt, grams/curb meter

P_{max} = maximum surface load for a particular subarea or landuse, grams/curb meter

b = loading coefficient, 1/days

Δt = buildup time interval, days

The exponential loading coefficient, b, in this equation was estimated to be 0.2 $days^{-1}$ from loading curves presented in Novotny and Chesters [1981] (i.e, the buildup half-time is 0.69/0.2 = 3.5 days). It is important to realize that this loading coefficient may vary depending on land use, location, and time, and that 0.2 was chosen as an average for model simplicity. The actual equation used in the model is the time derivative of equation 4.1 and is expressed as

$$\frac{dP_R}{dt} = b\left(P_{max} - P_R\right) \quad [4.2]$$

This equation allows for the computation of the incremental load as a function of accumulated pollutant buildup and eliminates the need for designating a starting time of the accumulation process. The value of P_{max} is input through the parameter maximum surface loading, **MSL**. P_R is the loading present on the surface after the previous storm event and is tracked by the model. The buildup time interval, Δt, is equivalent to the inter-event duration which is determined by the program using the product of the variables **IETI** and **IENPT**. Once the incremental loading is computed, it is added to the old value of P_R and is identified as the new initial surface loading, **ISL**, for the next storm.

Pollutant buildup may be highly dependent upon land use. To account for this, maximum loadings for the exponential equation may be varied from one subarea to another using the parameter **MSL**. Though sources in the literature do not give consistent results [Sartor and Boyd, 1972; Novotny and Chesters, 1981], the information in Table 4.5 gives results without the need for extraneous parameters such as daily traffic volume or road surface quality. The tabulated data in Table 4.5 was estimated from Figure 8.7 of Novotny and Chesters [1981].

Since the results of the loading equation has the units of grams/curb meter, a relation between curb length and land use is required to calculate surface loading in lbs/acre. Novotny and Chester [1981] reported sediment load (kilograms/hectare-year) versus percent impervious for various land uses. They also reported curb-length/hectare as a function of percent impervious [Figures 8.4 and 10.7 of Novotny and Chesters]. Upon examination of this information, a default curb-length per impervious zone area of 385 meters/hectare was adopted for the model. This curb length is available for change in the data file POLC.DAT (Table 4.1). The user must remember that this curb length factor is the average curb length per *impervious* hectare, i.e. percent impervious equal to 100%. Thus the surface loading of solids in the impervious zone is computed in the buildup routine as

$$\text{Surface Loading (lbs/acre)} = P_R \text{ (g/cb-m)} \times 385 \text{ (cb-m/ha)} / 453.6 \text{ (g/lb)} / 2.471 \text{ (acres/ha)}.$$

Table 4.5 Maximum street refuse accumulated for various land uses estimated from Figure 8.7 of Novotny and Chesters [1981]

Land use	Maximum loading, P_{max}, grams/curb meter
Commercial	180
Industrial	240
Residential	380
All land use categories	60

4.3.3 Dry Weather Removal

Pollutants are often removed during dry periods. The main removal mechanism is street cleaning, usually mechanized sweeping on a regular schedule. Other removal processes are wind erosion and extraneous water flow. These two processes have a minor impact on the pollutant surface load and are therfore not addressed by PSRM-QUAL.

Street cleaning is assumed to reduce the accumulated pollutant loading by some fraction. An extensive table of removal efficiencies as a function of pollutant and street cleaner type is given by Pitt [1979], a portion of which is shown in Table 4.6. Street sweeping at regular intervals creates a pollutant buildup function similar to that shown in Figure 4.1. The fractional removal obtained from sweeping to sweeping is dependent upon many details. These include cleaning frequency, amount of impervious area cleaned and pollutant concentration association of various sized particles (since particles may be differentially removed during the sweeping process). In the model, the sweeping routine assumes all particles are removed at the same fractional rate, regardless of size. Because of the high variability in fraction removed from one sweeping to another, the user is advised that caution should be used when applying this routine.

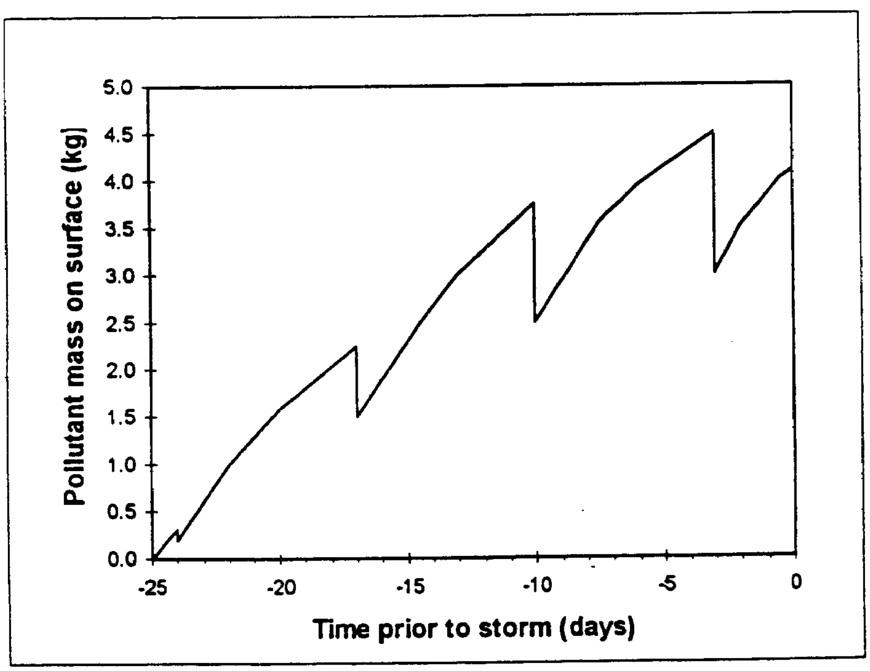


Figure 4.1 Typical effect of a 7-day street sweeping program on pollutant accumulation [Huber, et al, 1987]

Table 4.6 Removal efficiencies from street cleaner path for various street cleaning programs [Pitt, 1979]

Street cleaning programs / surface loading conditions	*Percent total solids removed*
Vacuum street cleaner / 5-50g/curb-meter total solids	
1 pass	31
2 pass	45
3 pass	53
Vacuum street cleaner / 50-280g/curb-meter total solids	
1 pass	37
2 pass	51
3 pass	58
Vacuum street cleaner / 50-500g/curb-meter total solids	
1 pass	48
2 pass	60
3 pass	63
Vacuum street cleaner / average for all loadings	
1 pass	39
2 pass	52
3 pass	58
Flusher	30
Mechanical street cleaner followed by a flusher	80

Note: Removal values assume all pollutants would lie within the street cleaner path (0 to 2.5 meters from the curb).

4.4 Pollutant Dislodging

Before washoff can occur, solids particles on the subarea surface must first be dislodged. In this model, it is assumed that particles are dislodged by the impact of raindrops, later to be eroded (washed off) by shear forces from runoff. An empirical formulation for sediment dislodging as developed by Sartor and Boyd [1972] has been adopted here as in many other urban runoff quality models. Once sediments are dislodged, then washoff is defined by equations of particle drag theory.

It should be understood by the user, that although the following formulations represent the state of the art in urban runoff quality modeling, these type of formulations always require calibration regardless of the level of sophistication of the component mechanisms.

4.4.1 Dislodging of Impervious Area Sediments

In this model, dislodging on impervious surfaces must occur before washoff is possible. The loosened particles are then available for transport by surface runoff as depicted in Figure 4.2. Experiments by Sartor and Boyd in Bakersfield, California indicated that a relationship exists between rainfall intensity and particle dislodging as described by

$$\frac{dN}{dt} = -kiN \qquad [4.3]$$

where: N = amount of particles of a given size range which may remain on the impervious surface at time t (mass/unit area)

t = time (minutes)

i = rainfall intensity over the area (inches/hour)

k = proportionality constant; dislodging coefficient (hr/inch-minute).

If the rainfall intensity is uniform for the specified time interval, then equation 4.3 can be treated as an ordinary differential equation. Solving the equation and expressing it in more convenient terms gives

$$N_c = N_o\left(1 - e^{-kit}\right) \qquad [4.4]$$

where: N_c = amount of particles of a given size range which are dislodged during time interval, t, of rainfall intensity, i.

N_o = initial unit area loading of the material of a given particle size which is available for washoff; a maximum value that could be washed off by a rainfall of intensity, i, even as t approaches infinity.

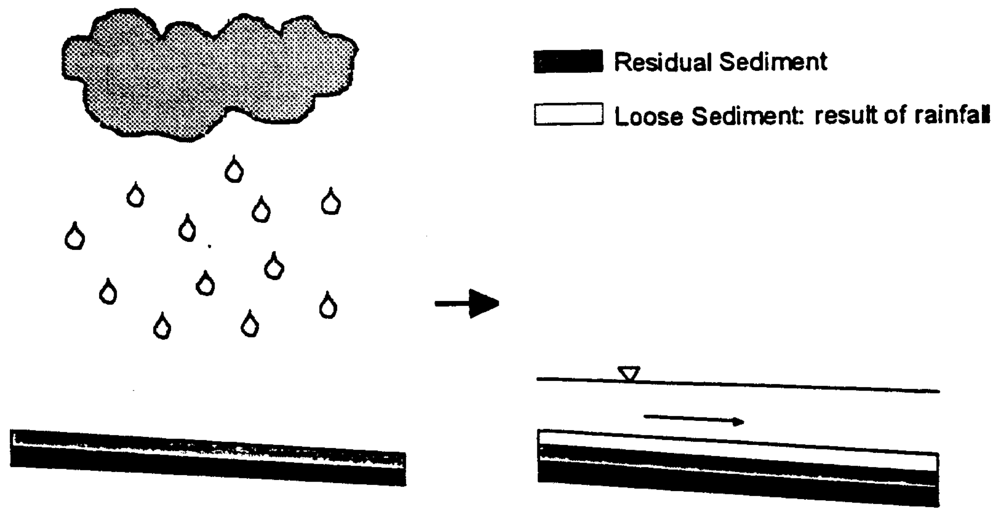


Figure 4.2 Particles loosened by the impact of rainfall.

The model applies equation 4.4 in the following fashion. After the initial surface load of sediments is determined (either as input ISL or after the buildup routine computes surface loading), the program distributes the total sediment load into the six particle size ranges defined for overland flow and places them in an array which is synonymous with N_o. The array has two dimensions of particle size range and hydrograph ordinate. Beginning with the first ordinate, the assocated rainfall intensity is determined. For each particle size range, the amont N_c of dislodged particles is computed based on the hydrograph time interval (HYDTI) and the dislodging coefficient, k, which is user input as SBK. N_o for the next time step becomes that which remains unloosened in the previous time step and the process is repeated for every time step and every particle size range in the storm.

Please note that because of the structure of the code in the model, the dislodging coefficient SBK must be entered in the units of 1/inch. A resonable number for SBK is somewhat difficult to determine. Mather [1992] examined the Sartor and Boyd dislodging study data (Sartor and Boyd, [1972]) and determined that SBK varied in that study between 2.4 and 17.8 inch^{-1}, with an average value of around 6.0. These studies dealt with asphalt and concrete surfaces and rainfall intensities of 0.2 and 0.8 inches/hour. The data file STDPARAM.DAT uses this value of 6.0 as the default for SBK. The user may find this parameter useful in the model calibration process.

4.4.2 Dislodging of Pervious Area Sediments

For all pervious areas, sediment erosion is computed by the Universal Soil Loss equation formulated by Wischmeier and Smith [1965] as shown in equation 4.7.

$$A_u = R_u K_u LS_u C_u P_u \tag{4.7}$$

where: A_u = computed soil loss in metric tons/hectare
R_u = rainfall erosion factor
K_u = soil erodability factor
LS_u = slope-length factor
C_u = cropping management factor
P_u = erosion control practice factor

The *rainfall erosion factor,* R_u , is usually computed as the sum of the rainfall erosion indicies during the period of predicition. For a single storm, R_u can be defined as

$$R_u = \Sigma\left[\left(1.15 + 0.57\log_{10} i_j\right)P_j\right]I_{30} \tag{4.8}$$

where: i_j = rainfall intensity during the time interval j, cm/hr
P_j = rainfall amount druing time interval j, cm
I_{30} = maximum 30 minute rainfall intensity, cm/hr
Q = runoff depth, cm
q = maximum runoff rate, cm/hr

In the model, the rainfall and runoff parameters are determined based upon the rainfall and subarea characteristics. There are no input parameters that affect this calculation directly. In the computer code, the value of I_{30} is set to 4 cm/hr as a reasonable maximum 30 minute rainfall intensity. The value of this parameter is not available for change by the user.

The *soil erodability factor,* K_u, is a factor of soil compostion, structure, and permeability. In the model, K_u is input as the subarea parameter **UK**. A value of K_u can best be obtained from data proposed by Stewart [1975] shown in Table 4.7.

Table 4.7 Soil erodability factors, K_u , adapted from Stewart, et al, [1975]

Textural Class	K_u for organic matter content (%)*		
	< 1/2 %	2 %	4 %
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	0.13 to 0.2		

* The values shown are estimated averages of broad ranges of specific soil values. When a texture is near the border line of two classes, use the average of the two K_u values.

The *length-slope factor*, LS_u, is expressed by the equation

$$LS_u = L^{0.5}\left(0.014 + 0.97S + 13.85S^2\right) \qquad [4.9]$$

where: L = length of the overland flow path, meters
S = slope of the overland flow path, meters/meter

In the model, L and S are defined by the subarea parameters **LENG** and **SLOPE** respectively.

The *cropping management factor*, C_u (subarea parameter UC), depends on the crop type or land use of the subarea. Values of C_u are presented in Table 4.8 as compiled from the works of Wishmeier and Smith [1965] and Stewart, et al [1975].

Table 4.8 Values of C_u for cropland, pasture, and woodland

Land Cover or Land Use	C_u
Continuous fallow tilled up and down slope	1.0
Shortly after seeding or harvesting	0.3-0.8
Crops during main part of growing season	
Corn	0.1-0.3
Wheat	0.05-0.15
Cotton	0.4
Soybeans	0.2-0.3
Meadow	0.01-0.02
Permanent pasture, idle land, unmanaged woodland	
Ground cover 95-100% as grass	0.003
Ground cover 95-100% as weeds	0.01
Ground cover 80% as grass	0.01
Ground cover 80% as weeds	0.04
Ground cover 60% as grass	0.04
Ground cover 60% as weeds	0.09
Managed woodland	
Tree canopy of 75-100%	0.001
Tree canopy of 40-75%	0.002-0.004
Tree canopy of 20-40%	0.003-0.01

The *erosion control practice factor,* P_u (subarea parameter UP), can be obtained from Tables 4.9 and 4.10 for construction sites and agricultural land, respectively.

Table 4.9 Values of P_u for construction sites adapted from Ports [1973].

Erosion Control Practice	P_u
Surface Condition with No Cover	
Compact, smooth, scraped with bulldozer or scraper up and down hill	1.30
Same as above, except raked with bulldozer and root-raked up and down hill	1.20
Compact, smooth scraped with bulldozer or scraper across the slope	1.20
Same as above, except raked with bulldozer and root-raked across slope	0.90
Loose as a disked plow layer	1.00
Rough irregular surface, equipment tracks in all directions	0.90
Loose with rough surface > 0.3 mm depth	0.80
Loose with smooth surface > 0.3 m depth	0.90
Structures	
Small sediment basins: 0.09 basins/ha	0.50
Small sediment basins: 0.13 basins/ha	0.30
Downstream sediment basins: with chemical flocculents	0.10
Downstream sediment basins: without chemical flocculents	0.20
Erosion control structures: normal rate usage	0.50
Erosion control structures: high rate usage	0.40
Strip building	0.75

Table 4.10 Values of P_u for agricultural land adapted from Wischmeier and Smith [1965].

	Strip cropping and terracing		
Slope (%)	Contouring	Alternate Meadows	Close-grown Crops
1.1-2.0	0.6	0.30	0.45
2.1-7.0	0.5	0.25	0.40
7.1-12.0	0.6	0.30	0.45
12.1-18.0	0.8	0.40	0.60
18.1-24.0	0.9	0.45	0.70
> 24.0	1.0		

4.5 Pollutant Washoff

Washoff may be defined as the process of erosion or solution of constituents from a subcatchment surface during a period of runoff. In the model, washoff calculations are parallel with kinematic wave runoff computations and therefore are done on a substrip basis for every hydrograph ordinate and every particle size range. Once surface particles are dislodged, washoff begins and it is assumed in this model that movement is caused by shear forces from runoff (see Figure 4.3).

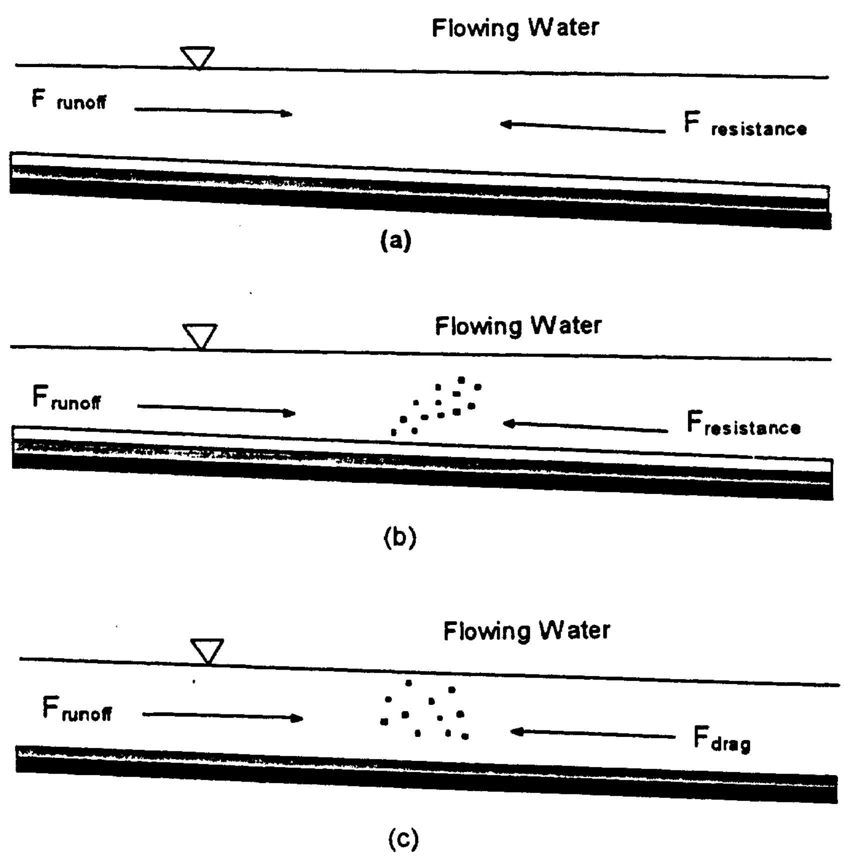


Figure 4.3 Sediment movement by runoff; (a) runoff forces have not yet overcome resisting forces; (b) runoff forces begin to overcome resisting forces and particles become suspended; (c) sediment movement is a relative velocity computed from runoff and drag forces.

In the development of a shear force relationship, opposing forces of drag and resistance on a particle must be evaluated. These forces can be represented by equations 4.10 and 4.11 respectively.

$$F_{drag} = C_d \pi r^2 (v_w - v_s)^2 \left(\frac{\gamma}{g}\right) \quad [4.10]$$

$$F_{resistance} = C_f (4/3) \pi r^3 (\gamma_s - \gamma_w) \quad [4.11]$$

where: C_d = Coefficient of drag

C_f = Dynamic friction factor

r = Median particle radius, ft

v_s = Sediment velocity of a given particle size, ft/sec

v_w = Velocity of runoff, fps

γ_s = Specific weight of the sediment, lb/ft^3

γ_w = Specific weight of water, 62.4 lb/ft^3

SG = Specific gravity of the sediment

g = gravitational constant, 32.2 ft/sec^2

Equating the drag force to the resistance force for the condition of incipient motion, where v_s equals zero, v_w equals the critical velocity of runoff, and the friction factor is based on static conditions, equation 4.12 results.

$$v_{cr} = \left[\frac{4}{3}\left(\frac{C_s}{C_d}\right) gr(SG-1)\right]^{1/2} \quad [4.12]$$

where: v_{cr} = critical velocity defining the condition of incipient motion

C_s = static coefficient of friction

The critical velocity required to cause motion for each particle size range is computed. The overland flow velocity as computed by the kinematic wave approximation is compared to this critical velocity. If overland flow velocity exceeds the critical velocity, then sediment movement exists on the overland substrip. Once motion begins, the static condition no longer applies and the velocity of the sediment must be computed by equating the drag force to the "dynamic" resistance force as expressed in equation 4.11. The relation to compute v_s becomes

$$v_s = v_w - \left[\frac{4}{3}\left(\frac{C_f}{C_d}\right)gr(SG-1)\right]^{1/2} \qquad [4.13]$$

Figure 4.4 is the plot of a form of equation 4.13, with the left side being changed to $v_w - v_s$. This curve is a good indication of how particle flow compares to fluid flow. Where Δv is low, particles are essentially mixed with the runoff and move almost as a continuum. For the very large particles, where Δv Is greatest, the particles are being "pushed" along with great resistance by the particle.

The amount of sediments washed off for a given particle size range on a given substrip is the product of the available sediment in the particle size range multiplied by the ratio of the distance traveled by the sediment during the hydrograph time interval to the overland substrip distance or

$$\text{Sediment washoff} = [(v_s \times \Delta t) / (\text{substrip distance})]\ (\text{Sediment available}) \qquad [4.14]$$

This ratio of sediment travel distance to substrip distance implies that prior to washoff for the time step in question, all sediments are evenly distributed across the substrip. Only those sediments that can travel far enough to reach the end of the substrip are "washed off" during the time interval. Those sediments that do not exit the substrip remain behind and become redistributed as part of the sediment available for washoff in the next time interval.

For this routine , the user inputs the subarea parameters **CD** (C_d) coefficient of drag, **DCF** (C_f) dynamic coefficient of friction, and **SCF** (C_s) static coefficient of friction. The specific gravity of the sediment, SG, is set to 2.65 in the computer code and cannot be changed by the user. All other parameters are computed by other routines in PSRM-QUAL.

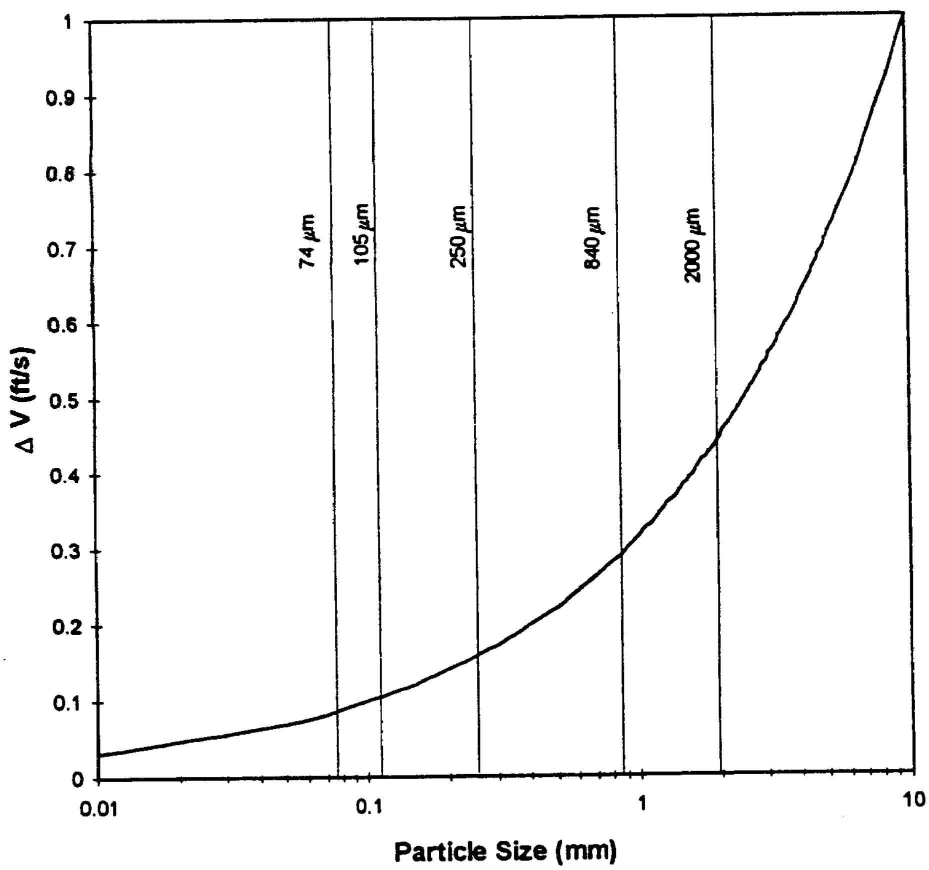


Figure 4.4 Velocity differential, $v_w - v_s$, for various particle sizes.

The washoff routine was one of the more time intensive routines in the original version of PSRM-QUAL, probably second only to the kinematic wave runoff routine. There were three sediment size ranges used in the original version, PSRMQ91. This number was increased to six for PSRMQ95 during the development of the BMP upgrade in order to improve the interface between the runoff routines and the BMP routines. The expansion of the washoff sediment arrays to the full thirteen groups as defined for the BMP routines in PSDIST.DAT would seem even more logical. However, computational speed would be reduced significantly and it is doubtful that such an increase in particle size range definition would increase the accuracy of the washoff routine. The thirteen groups were found necessary however, for reasonable results in the BMP routines.

4.6 Pollutant Transport Beyond the Subarea

Once the processes of buildup, dislodging and washoff is modeled for a subarea, a pollutograph of TSS (sediment graph) is created. This sediment graph may be combined with an upstream sediment graph or observed inflow sediment graph before being moved downstream to the next junction in the watershed flow network. Therefore, the model contains routines to handle channel routing, channel surcharge flow, observed flows.

4.6.1 Observed Hydrograph Sediment Loads

Prior to any drainage element routing, all upstream hydrographs of connecting draingage elements and their associated sediment graphs area added to the subarea hydrograph and sediment graph respectively. For reference here, this combined hydrograph will be called the drainage element hydrograph. At this point in the program, observed hydrographs identified as type 1 (inflow) for the subarea are added to the drainage element hydrograph. To handle the observed sediment load associated with the observed hydrograph, the user has the option to enter the observed hydrograph total sediment load (HTSL), which is the sum of all sediment associated with the complete observed hydrograph. This total sediment load is distributed among the observed hydrograph ordinates in the same proportion as the sediment load in the associated subarea hydrograph ordinates, that is for a given observed hydrograph ordinate

$$L_{OH}(i) = \mathbf{HTSL}\left(\frac{L_{SA}(i)}{\sum_{i=1}^{n} L_{SA}(i)}\right) \qquad [4.15]$$

where: $L_{OH}(i)$ = observed hydrograph ordinate sediment load, lbs

HTSL = observed hydrograph total sediment load, lbs

$L_{SA}(i)$ = subarea hydrograph ordinate sediment load, lbs

n = number of observed hydrograph ordinates

If the user elects to not provide a value for HTSL the program uses the pollutant concentrations in the subarea hydrograph to compute the sediment load graph for the observed hydrograph as

$$L_{OH}(i) = C_{SA}(i) \times Q_{OH}(i) \times \Delta t \qquad [4.16]$$

where: $C_{SA}(i)$ = subarea hydrograph ordinate sediment concentration, lb/ft^3

$Q_{OH}(i)$ = observed hydrograph flow rate, ft^3/sec

Δt = hydrograph time step, seconds

4.6.2 Drainage Element (Pipe or Channel) Routing

When routing a sediment graph through a given drainage element, the sediments are assumed to stay suspended in the flow without any settling. Additionally, the drag force on the particles is assumed to be negligible within the drainage element due to the higher flow velocities. This assumption permits the use of the Muskingum routing method as is used with the runoff flow described in section 3.7.1. As a result, the amount of translation and attenuation of the pollutograph will not differ from that of the hydrograph. For the case of dissolved pollutants, decay is considered to be negligible considering the relatively short time travel times for urban drainage elements.

4.6.3 Drainage Element Surcharge

Surcharge flow is defined as the flow that is in excess of the carrying capacity of the drainage element. This flow is considered out of bank or out of pipe. Sediments entering a drainage element are assumed to be equally distributed at all depths. As a result, the sediment concentration in the surcharge flow is assumed to be the same as that in the drainage element. Surcharge flow may actually washoff additional particles from the subarea surface. However, due to a likely decrease in flow velocity for surcharge, sediments in surcharge suspension may also settle out. As a result, the model assumes that potential washoff and settling in the surcharge flow negate each other and the sum result is zero change in sediment load in the surcharge flow.

As with drainage element routing, surcharge pollutants are assumed to have negligible drag forces due to high velocities (as compared to overland runoff velocities). The amount of translation and attenuation of the sediment graph is assumed to mirror that of the surcharge hydrograph. Surcharge routing is defined relative to drainage element routing by the user input parameter CTS.

4.7 Reservoir Considerations

In the original version of PSRM-QUAL, reservoirs used to abate runoff volume effects also were required to handle sediment loads. A complete mix routine was used in reservoirs to keep a mass balance of sediments, however there was no consideration given to settling effects. With the update to BMP routines in PSRMQ95, all reservoirs must be treated as BMPs if quality modeling is desired. See Chapter 6 of this manual for a description of the BMP modeling routines.

4.8 User Defined Conservative Organic Pollutants

PSRM-QUAL provides the user with the option to model one or two user defined conservative trace organic pollutants. This option assumes that the pollutants are associated to the total suspended solids in the runoff. The user must enter the name (eight characters maximum) for the pollutant, **ORGNAME$** and a pollutant concentration factor **ORGCONC**. This factor has the units of *grams per 1000 of solids* (μg/g) and is applied to TSS in a fashion similar to that of the factors of POLC.DAT. Table 4.11 lists the mean concentrations of several organic pollutants as determined by Novotny and Chesters [1981] for several cities in the United States. The standard deviations reported in this table illustrates the typical variability of runoff quality data found in the literature.

Table 4.11 Mean concentrations of organics in dust and dirt (μg/g); averages of several United States cities [Novotny and Chesters, 1981].

Constituent	*Concentration*	*Standard Deviation*
Endrin	0.00028	0.00078
Dieldrin	0.028	0.028
PCBs (overall)	0.78	0.76
Methoxychlor	0.5	1.1
Lindane	0.0022	0.0063
Mehylparathion	0.0024	0.0073
p, p-DDD	0.082	0.080
p, p-DDT	0.075	0.12

5

DETAILS OF POLLUTANT REMOVAL MODELING

5.1 Best Managment Practices and Removal Mechanisms

Removal of surface runoff pollutants in PSRM-QUAL is modeled through the use of best management practices (BMPs). These BMPs include detention basins, constructed wetlands, infiltration facilities and street sweeping. In order to create algorithms to physically model the removal processes of the various BMPs, a literature search was performed. Many removal mechanisms were identified, however only the mechanisms of grass filtration, sedimentation, resuspension, simple trapping and decay were chosen. It was decided that these pollutant removal processes would dovetail well with the existing runoff and quality routines of the model and provide enough physical information to adequately describe the removal processes. Keeping data input requirements to a minimum was also a criteria used to select these processes.

Table 5.1 Summary of BMPs used in PSRM-QUAL with associated removal mechanisms.

BMP	Application	Removal Mechanisms*
dry detention basin	in channel	F, S, R, D
dry extended detention basin	in channel	S, R, D
wet detention basin	in channel	S, R, D
constructed wetland	in channel	F, R, D
infiltration basin	small subarea only	T, D
infiltration trench	small subarea only	T, D
street sweeping	subarea specific	mechanical sweeper

* F = grass filtration, S = sedimentation, R = resuspension, D = decay, T = trapping

Not all mechanisms are used in every BMP. In addition, two of the BMPs were identified as only useful for small drainage areas while the remainder were identified as more appropriate for either small or large drainage areas. Table 5.1 summarizes the BMPs of PSRM-QUAL with their associated removal mechanisms and anticipated their application.

The following sections will discuss the mechanisms of removal identified in Table 5.1. The documentation of the complete literature search and algorithm development associated with this part of PSRM-QUAL can be found in the master's degree thesis of Ostrowski [1994]. It is hoped, however, that most of what the user needs to run the BMP options is provided within this manual.

5.2 Grass Filtration

Grass filtration of suspended sediments was chosen as a removal mechanism for the very early stages of flow through a BMP where ponding effects have not yet occurred and the BMP bottom acts like a vegetated buffer zone. Tollner, et al. [1976], investigated the effects of simulated vegetation on sediment removal and developed a relationship for trapping efficiency as

$$T_r = \exp\left[-\left(1.05 \times 10^{-3}\right)\left(\frac{vR_s}{\nu}\right)\left(\frac{Lv_s}{vd_f}\right)^{-0.91}\right] \qquad [5.1]$$

where: T_r = fraction of sediment trapped by vegetation,

v = velocity of flow through the vegetation, ft/sec,

ν = kinematic viscosity of the water, ft^2/sec,

L = length of the flow path, ft,

v_s = particle settling velocity, ft/sec,

d_f = depth of flow, ft,

R_s = spacing hydraulic radius, ft.

The spacing hydraulic radius uses the average distance between the grass blades and the depth of flow, d_f, to establish the ratio of flow area and wetted perimeter. Tollner defined R_s as

$$R_s = \frac{d_f S_s}{2d_f + S_s} \qquad [5.2]$$

where S_s is the average spacing between grass blades. Typical average grass spacing for some common grass types are given in Table 5.2.

Table 5.2 Typical grass spacing for four grass types [Hayes, 1976]

Density	*Grass Spacing, inches*			
	Sorghum	Fescue	Bluegrass	Ryegrass
Very Dense	0.504	0.217	0.374	0.307
Dense	0.571	0.295	0.433	0.402
Sparse	0.669	0.413	0.531	0.500

For every time step where filtration removal is applied, the computer calculates thirteen settling velocities (equation 5.4), one for each size range in the expanded particle size distribution. Removal rates are computed for each size range based upon the computed values of d_f, R_s, and v. Manning's equation is used to compute d_f and v, using **BOTEFL** of the resuspension routine and an estimated pond width from the BMP geometry implied in the ESO table. R_s is computed based upon the user input of **GRSPCG** along with d_f. The removal rates are then applied to the total sediment load in each size range of the time step to compute the removed sediment during the time step. In addition to **GRSPCG**, the user must enter values for **GRHGT** (grass height) and **STGDIM** (stage dimension). These two parameters are discussed in the sections dealing with the general removal procedures for the BMPs.

5.3 Sedimentation

Sedimentation is seen as the major pollutant removal mechanism for particulate pollutants when polluted stormwater is detained in a detention facility. These pollutants include suspended sediment and heavy metals which are associated to the sediment particles by adsorption. It is presumed that as sediment particles settle out of the water column, the metals associated with those settled particles will also be removed.

It is assumed in this model that particulate pollutants will settle out of the water column according to the following equation suggested by Driscoll [1988],

$$R_d = 1.0 - \left[1 + \frac{v_s}{n}\frac{DT}{h}\right]^{-n} \qquad [5.3]$$

where : R_d = fraction of solids removed under dynamic conditions,

v_s = particle settling velocity, ft/hr,

n = short circuiting constant,

h = depth of the basin, ft,

DT = detention time of the basin, hrs.

Detention time in the basin is based on the basin configuration, the outflow structure, and storm characteristics. Several definitions exist to define this time and a minimum detention time was chosen for this model and defined as

$$DT = \frac{V_{max}}{Q_{max}} \qquad [5.4]$$

where: V_{max} = maximum detention volume of the basin during the event, ft^3

Q_{max} = maximum outflow rate from the basin during the event, cfs.

This expression for detention time was chosen because it is a conservative estimate of detention time for all flow ordinates on the routed hydrograph. Early in the development of this routine, the detention time was computed for each time ordinate through the basin routing, based on the storage volume and outflow of the time step. It was found, however, that the use of the variable detention time would cause run-time errors in the computations under certain conditions. Also it was noted that for many comparison runs, the use of a variable DT as compared to the constant minimum DT did not appreciably affect the removal rates. Therefore, the constant minimum DT definition was adopted.

Reviewing equation 5.3, it is obvious that outlet structure geometry is very important in determining the performance of a basin using settling as a removal mechanism. If the user wishes to increase detention time for the modeling process, the outlet structure must be modified, since the outlet geometry controls the values of V_{max} and Q_{max}. The computer program determines the value of DT by tracking the maximum storage volume and maximum outflow rate for the storm event as the inflow hydrograph is routed through the BMP. In addition, pond depth, h, is stored as a function of time through out the routing for use in computing the removal efficiency of each time step. The values of the elevation-storage-outflow table, which define the basin geometry, will directly affect DT and h as well.

The short circuiting variable, n, in equation 5.3 is dependent on basin performance. The user will enter the parameter **SCN** (short circuiting number) to define n. One factor influencing short circuiting is the length to width ratio of the basin. A minimum length to width ratio of 3:1 should be used to reduce the influence of short circuiting under normal conditions. Another factor which can influence short circuiting is storm size. If a storm larger than the design storm is encountered, performance may again be reduced by short circuiting. Recommended values for this short circuiting variable were suggested by Fair and Geyer [1954] as shown in Table 5.3.

Table 5.3 Recommended values of SCN based upon performance of basin, Fair and Geyer [1954]

performance	n
poor	1
good	3
very good	5
ideal	∞

In a sensitivity study performed by Closson [1994], it was observed that n (SCN) did not affect the removal rate significantly for values of $n > 5$. That is, $n = 5$ and $n = 100$ gave very similar results and $n = 100$ and $n = \infty$ were practically identical.

The remaining variable in equation 5.3 is the particle settling velocity, v_s, and is computed based upon Stoke's Law which is

$$v_s = gd^2 \frac{(SG - 1)}{18\nu} \qquad [5.5]$$

where : v_s = particle settling velocity, ft/sec

d = particle diameter, ft,

g = gravitational constant, ft/sec^2

SG = specific gravity of the particle

ν = fluid kinematic viscosity, ft^2/sec.

Assuming that g, SG and ν are constant, the relation reduces to

$$v_s = Cd^2 \qquad [5.6]$$

where C is a lumped constant. In the surface runoff routines, the sediment particles are defined for six size ranges as presented in Figure 4.4. The particle settling velocities of the four larger ranges are very high and in most cases will settle out almost immediately in the basin. Therefore, once surface runoff enters a BMP, the finest surface runoff particle size range is expanded into a redefined distribution of eight particle size groups. This expansion from six size ranges to thirteen (6−1 +8) was found necessary for settling analysis. Most of the suspended solids that must be tracked are in this expanded range, that is, all the action is among the very fine particles, 74 microns and smaller.

In the program, the particle size distribution for the sediments entering a BMP are defined in the data file PSDIST.DAT as shown in Table 4.3. This distribution was created by averaging several particle size distributions of sediments entering BMPs that were reported in the literature. This distribution should be examined by the user, and if possible, modified to match the sediment characteristics observed in pre-BMP runoff in the watershed.

The mean particle size diameter for a given range is used to compute the settling velocity of equation 5.6. This mean diameter is computed in the program and is nothing more than the arithmetic average of the upper and lower limits of the range specified in PSDIST.DAT. The values of g (32.2 ft/sec^2), SG (2.65) and ν (1.41×10^{-5} ft^2/sec) are written directly into the PSRM-QUAL code and are not available for modification by the user.

For every time step in the routing of sediments through a basin, the computer calculates thirteen settling velocities, one for each size range in the expanded sediment distribution. Removal rates are then computed for each size range based upon the constants DT and n, and h which varies for each time step. These removal rates are then applied to the total sediment load in each size range of the time step to compute the removed sediment during the time step. Overall sediment removal during the event is the sum of all sediment losses of all particle size ranges for all time steps during the routing of the sediment graph.

5.4 Resuspension

The issue of resuspension is very important when calculating the overall efficiency of pollutant removal in a detention basin or wetland. However, little is known about the modeling of resuspension in these facilities. As an approximation to the resuspension process the duBoys equation for channel sediment movement was adopted for the model. This equation is relatively familiar to practicing engineers and the data input requirements are minimal.

The first assumption of the duBoys equation is that the channel can be assumed as wide and shallow, thereby neglecting any effects due to channel sides. For detention basins and wetlands, this assumption is roughly valid since the ratio of depth to width is usually small. For two dimensional flow, the duBoys equation to predict bed load is

$$g_s = \Psi DS\left(DS - \frac{\tau_i}{g}\right) \qquad [5.7]$$

where: g_s = bed load in pounds per foot of width

D = depth of flow in feet,

S = slope of the flow path in ft/ft,

τ_i = critical tractive stress exerted on the bed, lb/ft^2.

Ψ = sediment characteristic which varies with particle size, lb/ft^3-sec.

The following relation can be used to predict the Ψ value,

$$\Psi = \frac{111{,}000}{d_m^{3/4}} \qquad [5.8]$$

where d_m is the mean diameter (millimeters) of the sediment in the basin bed. The program computes a mean particle diameter for the total bottom sediment load based upon the bottom sediment particle size distribution defined in the file PSDIST.DAT. The resuspended load Is computed for each hydrograph ordinate as a single lumped sum in pounds. This load is then distributed among the particle size ranges for every hydrograph ordinate according to the bottom sediment distribution of PSDIST.DAT.

Equation 5.7 can be simplified by assuming that the tractive critical stress is negligible since this value is small. Also, if Manning's equation is used to calculate the value of depth expressed in terms of average velocity, v, this equation can further be simplified to

$$g_s = \Psi S^{1/2}\left(\frac{n}{1.5}\right)^3 v^3 \qquad [5.9]$$

where: n = Manning's roughness coefficient for the basin bottom,

v = average flow velocity, ft/sec,

S = slope of the basin bottom, ft/ft.

Equations 5.8 and 5.9 are the equations used in the resuspension routine to compute resuspended sediment loads for BMPs. The calculation of the average flow velocity is based upon the depth of water in the facility. If ponding effects are not significant, then the Manning's equation is used. When ponding effects are significant, the average flow through velocity is computed based upon gross dimension of the detention facility to estimate flow through area, then using $v = Q/A$. The user must input the parameters **BOTEFL** (bottom effective length), **BOTMN** (bottom Manning's n), **BOTSLP** (bottom friction slope), and **VBOTSED** (volume of bottom sediments available for resuspension).

During the development of this routine, it was observed that the duBoys equation would consistently over estimate resuspended load in a basin. In order to resolve this problem the computed resuspended load in the program is adjusted by a factor between 0 and 1. Currently this factor is 0.1.

5.5 Simple Trapping

Simple trapping is nothing more than retention of runoff water which is only released through infiltration, transpiration or evaporation. In this model, only surface runoff is tracked for mass balance calculations. Therefore, in the case of infiltration basins and trenches, pollutants are assumed completely removed from the runoff for those hydrograph ordinates that are "trapped" by the infiltration facility. Once overflow occurs for the facility, then all pollutants are assumed to be passed through the BMP without any removal. Efficiency is computed during the mass balance process, where total pollutograph outflows (overflows) are compared to total pollutograph inflows to compute the event mean concentrations. Simple trapping is explained in further detail in sections 5.7.5 and 5.7.6 of this manual.

5.6 Decay Rates for Dissolved Species

During the sediment wash-off process in the runoff routines, the model assumes that all pollutants are associated to suspended solids. The program uses the content of POLC.DAT to determine the amount of each pollutant present in the runoff. Once these pollutants enter a BMP, this association of pollutants to sediment particles breaks down for pollutants that are also found in the dissolved fraction. The concentration of these species may change as a result of biological and chemical reactions that occur during the detention time period. In PSRM-QUAL the dissolved pollutants are total Kjeldahl nitrogen (TKN), nitrates and nitrites (NO_2 and NO_3), total phosphorus (TP), soluble phosphorous(SP), chemical oxygen demand (COD) and biochemical oxygen demand (BOD).

Upon exiting a subarea runoff analysis, all pollutants with a dissolved fraction are split into two parts; a sediment associated portion and a dissolved portion. The model treats each part differently. The dissolved portion is removed by the first order decay relation of equation 5.10. The user provides the magnitude of the dissolved fraction of the pollutant in the file DECAY.DAT, the content of which is shown in Table 5.4. This table also contains the decay coefficients for each dissolved pollutant. The dissolved fractions of DECAY.DAT are used with the pollutant association factors of POLC.DAT to determine the total load of dissolved pollutants entering a BMP.

The sediment associated portion (adsorbed fraction) is simply computed as the total sediment load multiplied by the appropriate pollutant association factor and one minus the dissolved fraction coefficient. Removal of the adsorbed fraction from the stormwater (in a BMP) is only by the removal mechanisms for sediments. This portion remains separated from the dissolved fraction throughout the modeling process of the watershed and is combined with the dissolved fraction only when outflow concentrations are computed for the OUT file.

All dissolved pollutants in PSRM-QUAL are allowed to decay or grow according to the first order relationship

$$C_t = C_o e^{-kt} \qquad [5.10]$$

where: C_t = pollutant concentration at time t

C_o = pollutant concentration at time zero,

k = pollutant decay coefficient (base e), days^{-1}

t = detention time, days

Table 5.4 Dissolved pollutant removal data contained in the data file DECAY.DAT

```
DECAY.DAT: Pollutant BMP Decay Factors for PSRM-QUAL
 Pollutant decay coefficients in 1/days
      TKN  NO2+NO3       TP       SP      COD      BOD
    -0.06    -0.01    -0.15    -0.01    -0.20    -0.20
 Dissolved fractions
     0.33     1.00     0.15     1.00     1.00     1.00
```

If k is a negative value, then the decay coefficient becomes a formation coefficient. This could occur due to nitrification (increase of NO_2+NO_3) or mineralization of organic materials (increase in dissolved phosphorus). These processes are not well-understood. As a result, the only decay rate coefficients that currently have non-zero values are for decay of BOD and COD.

When a sediment graph enters a BMP, an associated array containing the dissolved pollutant loading also enters the BMP. This two dimensional array contains the total load of each dissolved pollutant for each time step in the hydrograph. In this array there is no definition of particle size ranges, since PSRM-QUAL currently does not associate pollutants to sediments based on particle size. For every ordinate in each pollutograph, equation 5.10 is applied where C_o is the incoming pollutant load and C_t is the outgoing pollutant load, applying the constant DT defined by equation 5.2. The rate of pollutant decay is set by the user by accessing the data file DECAY.DAT. This file contains default decay rates for all six dissolved pollutants. Users are strongly encouraged to review these coefficients and modify them as necessary to match the conditions of the stormwater runoff in the watershed.

5.7 General Removal Procedures for the BMPs

During the runoff process, sediments are dislodged and washed off according to the mechanisms described in chapters 3 and 4. As calculations of runoff travel from subarea to subarea, the pollutants are tracked, added and stored in a set of three arrays. These arrays are TSED (total sediment), CPOLL (conservative pollutants) and DPOLL (dissolved pollutants). These arrays are essentially two dimensional (they are actually three dimensional, but the third dimension is of no importance here).

TSED is dimensioned for particle size range (6 or 13 depending on runoff or BMP calculations) and flow ordinate. This array keeps track of all the sediment loads in each particle size range for each time step. Only TSS is contained in this array. As mentioned in earlier parts of this manual, there are six particle size ranges tracked during runoff calculations and these six are expanded to thirteen to assist in tracking sediment removal when flow is passed through a BMP.

CPOLL is dimensioned for conservative pollutants (4 to 6 depending on the use of user defined organics) and flow ordinate. This array keeps track of the total load of each pollutant in each time step as determined through the respective pollution concentration factors present in the POLC.DAT data file. Since land use can vary from subarea to subarea, the POLC factors must be applied at every subarea calculation. As sediments are tracked from subarea to subarea, the POLC factors at a given point along the drainage network are a sediment load weighted average of that shown in POLC.DAT depending on the variation of land use for all subareas above the drainage node. Thus the total load of conservative and dissolved pollutants must be tracked independent of total sediment once runoff calculations pass beyond the first subarea. CPOLL contains the pollutants of TSS, Cu, Zn, Pb and up to two user defined trace organics. Note that TSS is redundant to that which is already contained in TSED, except that TSS in CPOLL is a summation of all particle size range sediment loads in each time step.

DPOLL is dimensioned for six dissolved pollutants and flow ordinates. Its purpose is similar to CPOLL as described in the above paragraph. DPOLL contains the pollutants of TKN, NO2+NO3, TP, SP, COD and BOD.

Prior to removing sediment or other pollutants in the stormwater, every BMP goes through a hydraulic routing routine. The inflow hydrograph is by the Modified Puls routing procedure as described in section 3.8 of this manual for all BMPs except the constructed wetland. This routine returns the complete inflow hydrograph, the complete outflow hydrograph, and a time variable array of basin storage volume. The constructed wetland routing routine uses the kinematic wave relation to estimate flow depths in the wetland over time. These depths are converted to flowrates and estimated storage, providing output consistent with that provided by the Modified Puls routing.

A second routine is called to compute the basin detention time as defined in equation 5.4 along with pond depth for every time step. Pond depth is determined by interpolating on the elevation-storage-outflow table, knowing the basin storage volume from the routing and also knowing the basin bottom elevation, **BOTEL**, from user input. Detention time is used in the decay and settling routines. Pond depth is used in the settling routing to determine the settling column height. Pond depth is also used in the resuspension routine to assist in computing an average flow through velocity for every time step. Once these parameters are determined, the appropriate removal routines are called as described below. Note that the pond depth calculation is not used for the constructed wetland. Depths are already computed in the wetland routing.

5.7.1 Dry Detention Basin (DDB)

The DDB uses four of the removal mechanisms to model removal efficiency. Prior to a storm event the basin is assumed to be empty. When storm runoff begins to flow into the facility, the algorithm assumes that the runoff will flow through the basin basin bottom vegetation with a shallow depth. During this phase, the filtration routine is used to estimate sediment removal using equations 5.1 and 5.2. Also during this first phase, the resupsension routine is being used to predict the amount of bottom sediment that is added to the storm runoff due to erosion activity in the basin bottom. This routine will counter-act the filtration routine.

At some point in the basin routing, ponding effects will overtake the filtration process on the basin bottom. In the algorithm, the program compares the magnitude of **GRHGT** (grass height) against another user input called **STGDIM** (first stage dimension). The smaller dimension of the two is used as the break point on pond depth where the filtration routine ends and the settling routine takes over.

Whenever the pond depth is determined to be greater than the minimum value of **GRHGT** and **STGDIM**, the settling routine is used for sediment removal instead of filtration. Removal rates are computed based upon equation 5.4. It should be noted that if pond depth ever falls below the minimum of GRHGT and STGDIM, the removal mechanism returns to filtration.

After each time step the amount of removed sediment (by filtration or sedimentation) and the amount of added sediment (by resuspension) are totaled and completely mixed in the runoff storage volume in the basin. From this information, a basin sediment concentration is computed. The outflow load is then computed based upon the basin sediment concentration, the outflow rate and the routing time step.

During all of the filtration, settling and resuspension activity, the decay routine is also operating on the dissolved pollutant array. For each inflow ordinate, the decay relation of equation 5.10 is used to reduce these pollutant loads.

5.7.2 Dry Extended Detention Basin (DXDB)

The DXDB uses three removal routines, namely settling, resuspension and decay. The algorithm is similar to the DDB algorithm, except filtration is never used. Thus during the initial phase of inflow to the DXDB, settling is used immediately. The decision to not use filtration for this BMP was based on a review of the literature and the reported efficiencies of DXDBs. Consistently, the removal efficiencies were reported to be very similar to those observed for wet detention basins. Therefore, the DXDB algorithm was chosen to be identical to that of the wet detention basin as described in the next section.

5.7.3 Wet Detention Basin (WDB)

The WDB (and DXDB) algorithm uses settling, resuspension and decay. In addition, the condition of a pre-storm wet pond is certain for the WDB and possible for the DXDB. Therefore, the user must enter the initial concentrations in the basin of seven pollutants, namely TSSo, TKNo, NO2P3o, TPo, SPo, CODo and BODo. Since Cu, Zn, Pb, and the optional trace organics are conservatives, the algorithm assumes that the ratio of TSS/CPOLL entering the basin is the same as the ratio of TSS/CPOLL in the initial concentration in the ponded water. Thus initial concentrations for the metals and trace organics are not needed as input by the user.

It is worth noting here, that the user must keep the content of POLC.DAT and DECAY.DAT in mind when entering the initial concentrations required in this algorithm. In order for the pollutant output of the BMP to be reasonable in the early portions of the output (the first few time steps), the initial concentration **TSSo** and the dissolved pollutants must be on relatively consistent basis. For instance, if TP is 15% dissolved, **TSSo** equals 50 mg/l, and the TP to TSS pollutant association factor in POLC.DAT is 0.379 g/100g, then **TPo** for the basin should be on the order of magnitude of

$$(50 \text{ mg/l}) \times (0.00379 \text{ g TP/g TSS}) \times (0.15) = 0.028 \text{ mg/l.}$$

Prior to runoff entering the pond, the total suspended load of pollutants in the basin is computed for each pollutant based upon initial concentrations in the basin and the initial basin storage volume. Initial storage volume is determine by interpolation on the elevation-storage-outflow table using the input parameter **IWSE** (initial water surface elevation). The initial suspended solids load in the basin is distributed among the particle size ranges according to the "Suspended Solids Distribution" presented in PSDIST.DAT. As is the case for all DAT files, the user should verify or modify the content of this file to meet site specific conditions.

When runoff enters the pond, the resuspension routine is called. The total sediment load resuspended in each particle size range is computed and added to the suspended load in the basin. The settling routine is then called and sediments are removed by equation 5.4. The total suspended load is then updated by subtracting the settled load from the suspended load. The settled load is added to the bottom sediment load, which is made available for resuspension in the next time step. The basin sediment concentration for the time step is computed assuming a complete mix condition. Finally, the outflow load is computed using the basin sediment concentration, the outflow rate and the time step. This sequence is repeated until all inflow points have been passed through the BMP.

It is worth noting, that in the resuspension routine, only available bottom sediments can be resuspended. If **VBOTSED** is exhausted through previous removal steps, then only those sediments which were deposited by the settling routine in prior steps are available for resuspension.

As in the case of the DDB, the decay routine is always operating in the background on the dissolved pollutant array.

5.7.4 Constructed Wetland (CW)

In the CW algorithm, the flow routing process is the kinematic wave overland flow routine. This routine is very similar to the kinematic wave routine used to compute surface runoff as described in section 3.6 of this manual. This routine returns inflow hydrograph, outflow hydrograph, and flow depths for each time step. Using the output of the CW kinematic wave routine, the CW pollutant removal algorithm utilizes the removal routines of resuspension, filtration and decay.

In modeling overland flow in wetlands, certain characteristics of the wetland should be considered. Most important is the degree of obstruction that runoff will encounter as it flows through the wetland. Surface roughness is defined by the input parameter **CWBMN** (CW bottom Manning's n). Other parameters input by the user to define the CW routing routine include **CWBEFL** (CW bottom effective length), **CWBSLP** (CW bottom slope), **CWYINI** (CW initial depth), and **CWWDTH** (CW average width).

The detention time of the CW is defined as the travel time of the runoff from the inlet of the wetland to the outlet of the wetland. This travel time, t, is based on kinematic wave theory and is calculated as

$$t = \frac{(nL)^{0.6}}{1.49^{0.6} i^{0.4} S^{0.3}} \qquad [5.11]$$

where: t = travel time in hours,

n = Manning's roughness coefficient,

L = length of flow in feet,

i = characteristic rainfall intensity in feet/hr,

S = wetland slope in ft/ft.

If a significant amount of ponding occurs in the constructed wetland during a event, the WDB algorithm may be more appropriate for modeling the pollutant removal in the wetland. This would necessitate the creation of an elevation-storage-outflow table for the wetland. This may be difficult however, if the wetland does not have a well defined outlet structure.

5.7.5 Infiltration Basin (IB)

In the IB algorithm, the Modified Puls routing is used to determine the basin outflow and storage for each time step. The routing for the IB, however, is somewhat different than that explained in section 3.8, since there is no "structural" outlet control. Yim and Sternberg [1987] developed a methodology to compute outflows from infiltration facilities and it is used here. The outflows for the IB are a function of the wet surface area of the basin bottom and sides, and the hydraulic head caused by the ponded water. The algorithm allows the user to define the infiltration geometry as either (1) trapezoidal or (2) conical. For the trapezoidal IB the basin exfiltration outflow is computed by the relation

$$O_2 = I_h\left[\frac{2H_w^2}{\tan\alpha\sin\alpha} + \left(W_b + L_b\right)\left(1 + \frac{H_w}{\sin\alpha}\right)\right] \qquad [5.12]$$

where: O_2 = basin exfiltration outflow, cfs

I_h = infiltration rate as a function of hydraulic head, ft/sec (entered by the user in in/hr)

H_w = average hydraulic head, ft

W_b = bottom width of the basin, ft

L_b = bottom length of the basin, ft

α = angle of side slope from the horizontal, degrees

A similar equation for the conical basin was developed as

$$O_2 = I_h\left\{\pi R_1^2 + \frac{1}{2}\left[\pi\left(R_1 + R_2\right)\sqrt{\left(R_1 - R_2\right)^2 + H_w^{\,2}}\right]\right\} \qquad [5.13]$$

where: R_1 = bottom radius of the basin, ft

R_2 = top radius of the basin, ft

At each computation step the algorithm estimates an average head in the basin based upon the inflow and previous storage depth. Using this average head, an infiltration rate, I_h, is interpolated from a head-infiltration table entered by the user. Using I_h, the basin exfiltration flow is compute via equations 5.12 or 5.13. The basin storage is then computed from the routing procedure and a final head (water depth) is computed for the end of the time interval.

During any given routing interval, if the computed exfiltration outflow, O_2, is less than the inflow, O_1, and the basin is full of runoff, then overflow will occur and be computed as the difference between inflow and exfiltration outflow. For time steps where overflow occurs, pollutants are released from the IB to the downstream drainage element. Pollutant loads in the overflow are computed proportionally to the pollutant loads in the inflow as

$$P_{overflow} = P_{inflow} \frac{Q_{overflow}}{Q_{inflow}} \qquad [5.14]$$

For periods where the basin is capable of trapping all of the incoming runoff, the pollutant load discharged to the downstream drainage element is zero, and pollutants are assumed to be 100% removed.

For this algorithm, the user must enter a subset of the following parameters of **IFGEOM** (infiltration facility geometry), **IFBWDTH** (infiltration facility bottom width, W_b), **IFBLEN** (infiltration facility bottom length, L_b), **IFDPTH** (infiltration facility depth), **IFBDIA** (infiltration facility bottom diameter, $2R_1$), and **IFHSS** (infiltration facility horizontal side slope, replaces α). The content of the parameter subset is determined by the value of **IFGEOM**.

5.7.6 Infiltration Trench (IT)

The IT algorithm is very similar to the IB algorithm except the geometry description is slightly different. Infiltration trenches are assumed to be filled with porous aggregate. The user input parameter to define aggregate porosity is **IFPOR**. Trench water depths are adjusted using **IFPOR** and the value of storage volume computed in the routing step.

All trenches must have a trapezoidal geometry. If vertical side slopes are desired, then the user must enter a value of 0 for **IFHSS**. For trenches with sloping sides, equation 5.12 is used to compute the exfiltration outflow. For the case of vertical side slopes a simpler relation is used, specifically

$$O_2 = I_h\left(W_b L_b + H_w W_b + H_w L_b\right) \qquad [5.15]$$

where all terms are as previously defined.

A more detailed explanation of the inflitration basin and infiltration trench routines of PSRM-QUAL can be found in a report by Brown,et al. [1994].

5.8 Default Method of Pollutant Removal

The algorithm offers a default option to calculate pollutant removal for dry detention basins, dry extended detention basins, wet detention basins and constructed wetlands. No default option is available for infiltration facilities. These default options may be used as an initial run to estimate the performance of a certain BMP prior to data accumulation or as an alternate method when sufficient data is not available to use the removal mechanism relations. While these options are offered as alternatives to the specific removal mechanisms, they are certainly very approximate and should be considered as a "ballpark" estimate at best.

The default routines all work in a similar fashion for the four BMPs. The inflow hydrograph is routed through the detention facility in order to determine the time shift between the inflow hydrograph peak and the outflow hydrograph peak. For multiple storms, this peak shift is computed for every storm event. The first storm inflow pollutograph is moved forward in time through it's peak shift time, with the tail of the pollutograph being pushed into the next storm segment. The tail of the shifted pollutograph is simply clipped or stretched to account for any overlap or gaps to the next storm's shifted pollutograph. All ordinates along the pollutograph are then reduced by the appropriate removal fraction found in the data file REMRATES.DAT. The contents of this file is shown in Table 5.5.

The values in this table were compiled from Schueler [1987], Schueler, et al. [1992], Strecker, et al. [1992] and Yu, et al. [1993]. In many cases, these values were established on a very small data base. In a few cases the value was based on the performance of one BMP! *It is highly recommended that the user establish estimates of watershed specific rates and modify the contents of* REMRATES.DAT *before using the default option of the model.*

Table 5.5 Default removal rates for pollutants contained in the data file REMRATES.DAT

Pollutant	Dry Detention Basin	Dry Extended Detention Basin	Wet Detention Basin	Constructed Wetlands
TSS	+ 0.14	+ 0.46	+ 0.70	+ 0.67
Cu	*	+ 0.31	+ 0.66	− 0.21
Zn	− 0.10	+ 0.23	+ 0.57	+ 0.30
Pb	− 0.05	+ 0.46	+ 0.66	+ 0.61
TKN	+ 0.10	+ 0.30	+ 0.32	+ 0.16
NO_2+NO_3	*	+ 0.18	+ 0.49	+ 0.52
TP	+ 0.20	+ 0.25	+ 0.52	+ 0.38
SP	*	− 0.09	*	+ 0.07
COD	*	+ 0.21	+ 0.52	+ 0.27
BOD	*	+ 0.35	+ 0.34	− 0.10

* No removal rate for the pollutant in the specified BMP was found in the literature.

5.9 Event Mean Concentrations

Event mean concentrations (EMCs) in appropriate units of mass/volume, are computed for each pollutant in every printed pollutograph. The EMCs are computed based upon the following relation

$$EMC = \frac{\sum_{n}^{i=1}(P_i)}{\sum_{n}^{i=1}(Q_i \Delta t)} \qquad [5.16]$$

where: P_i = pollutant load (mass),

Q_i = flow rate (runoff volume per unit time),

Δt = routing time interval (unit time),

n = number of routing intervals during the event.

Since this definition of EMC is based on inflow and outflow volumes, it is important that the user provide enough computation intervals to return the BMP to the storage condition similar to the pre-event condition. Basins that remain half or completely full after a runoff analysis may cause the program to report EMCs higher than expected because the calculation is made only for the duration of runoff specified by the user through the parameters **HYDTI** and **HYDNPT**.

5.10 Mechanical Sweeping

Street sweeping as mentioned earlier, can be classified as an non-structural BMP. Many municipalities and shopping mall management authorities sweep paved areas on a regular schedule. Removal efficiencies vary depending on typical surface loadings, equipment used and sweeping procedures. Section 4.2.3. "Dry Weather Removal," of this manual describes the street sweeping algorithm in PSRM-QUAL.

6

FILE CREATE INSTRUCTIONS

A new input file for PSRM-QUAL should be created through Option 1 of the program's main menu. All input files are given the extension .INP by the program. The data input is organized into logical data blocks. The data blocks are defined as:

1. File Definition
2. Watershed Elements
3. Time Parameters
4. Rainfall Parameters
5. Standard Subarea and Drainage Element Parameters
6. Subarea Parameters
7. Organic Compounds
8. Drainage Element Parameters
9. Reservoir Parameters
10. BMP Parameters
11. Observed or Inflow Hydrograph Parameters

The program will prompt the user for input parameters in a generally self-explanatory way. The additional information that follows here should clarify each parameter's use and minimize the chance for incorrect data input.

In the following listing of parameters, **BOLD** type names are parameters that are direclty input by the user through the file creation routine of Option 1 of the main menu. Other parameters that are not bold type are parameters that are not entered by the user, however they may show up in the INP file listing.

6.1 File Definition

The initial block of data establishes the file type and allows the user to enter up to five lines of text describing the content of the file. The user must press RETURN after each headline entered; and after the last line, press RETURN without entry. The program will count the number of heading lines (NHL) and record this number in the INPut file. Users must be careful when editing the INPut file with the MS-DOS EDIT program. The value of NHL must match the actual number of headlines, otherwise the file will become unreadable by PSRM-QUAL. ***Also note that commas must not be entered in any heading line. Commas will make the file unreadable.***

The date and time of file creation are also recorded in this block by the computer clock and are provided as a reference for original file creation.

Variable	Description
Filename	Name of the input file being created. This name follows the DOS rules for filenames. See your DOS manual for complete details.
QualFile	Defines the file as quantity only (0) or quantity with quality (1)
NHL	**Number of heading lines** in the file definition block. This parameter can vary from 0 to 5 depending on user input.
DATE$, TIME$	Date and time when the file was created. This parameter is entered automatically from the computer clock and is for user reference only. The user has no chance to enter or edit this parameter in the file create routine.

6.2 Watershed Elements

The watershed elements block establishes global values for the watershed and event(s) defined in the file.

Variable	Description
NSA	Number of SubAreas. The value of this parameter must be at least 1. The maximum number of subareas which PSRM-QUAL can handle will be a function of the amount of computer memory (RAM) that is available when the file is run under Option 3 of the main menu.

NST Number of STorms. This parameter should be set to 1 if the model is to be used in the traditional single event fashion. If the peak fow presentation option is being used then NST must be set to 1. This parameter should be greater than 1 if the user wishes to model a complex rainfall. A complex rainfall is defined as one that contains a number of discretely defined rainfall segments each separated by a significant period of no rain. The no-rain period is defined as the inter-event segment. Each storm beyond the first has a rainfall segment and an associated preceeding inter-event segment. See the Time Parameters data block later in this chapter for more information. A practical limit to the number of storms that can be modeled during a single run has been arbitrarily set to eight. Therefore, NST must range between 1 and 8.

STOPT STorm OPTion. This parameter must have a value of 0 to 3. The storm options are:

0 = observed rainfall (manually entered hyetograph)
1 = synthetic rainfall using PDT-IDF curves
2 = synthetic rainfall using SCS Type I, II, III rainfall distributions
3 = synthetic rainfall using USWB IDF curves (Yarnell equations)

NPRT Number of subareas with PRinTed output. This number must be at least 1 and no greater than NSA. Hydrographs and pollutographs will be printed to the output (OUT) file for this number of subareas. The user will later identify these subareas by number. Printout of computation results for a subarea will not be provided by the program unless specifically requested by the user. Print out is limited in this fashion in an effort to minimize the size of the output file. If output is desired for all subareas, then set this parameter equal to NSA.

NOBS Number of subareas with OBServed (or inflow) hydrographs. This number must not exceed NSA. Each subarea is permitted to have an associated observed hydrograph or inflow hydrograph. The user will later enter the subarea identification number and hydrograph type (HTYP). If the observed hydrograph option is not needed, then set this number to 0. See the Optional Subarea Data block description of this chapter for further details.

NPFP — Number of subareas with Peak Flow Presentations. This number must not exceed NSA and is typically a low number. Peak flow presentations provide large amounts of output when NSA is large. This option should be used with discretion. A good understanding of the peak flow presentation computational procedure is imperative to completely understand the output results. If the peak flow presentation option is not needed, then set this number to 0.

NOTE: The peak flow presentation option is not available for use in PSRM-QUAL at this time. Future versions will restore this option.

NRES — Number of subareas with REServoirs. This number must not exceed NSA. Set this number to 0 if the watershed contains no reservoirs. The program will automatically set this number to 0 if the "quantity with quality" option has been chosen. The user will later enter the subarea identification number of each subarea that contains a reservoir. Reservoirs can be of two types (RTYP) and this information is entered later in the Optional Subarea Data block.

NBMP — Number of subareas with BMPs. This number is the counter part to NRES and must not exceed NSA. Within the context of PSRM-QUAL, BMP means a structural device that has the ability to remove sediments from urban runoff. If the "quantity only" option is chosen, the program automatically sets NBMP to 0. If no BMPs are in place in the watershed then set this value to 0. The user will later enter the subarea identification number for each BMP. Significantly more information is needed to describe the physical characteristics of a BMP as compared to a reservoir. See the Optional Subarea Data section later in this chapter for more information on BMPs.

NORG — Number of user identified ORGanic pollutants. This number is offered as input only if the quality option is chosen. The user may define one or two conservative trace organic compounds to be modeled in the quality routine. These compounds will be entered later after the subarea data entry routine. The program internally sets this parameter equal to 0 if the quality mode is not invoked.

6.3 Time Parameters

The time parameters block contains hyetograph and hydrograph (pollutograph) timing information for each storm event. Storm events can be simple single storm events or complex multiple storm events with associated inter-event periods of no rainfall. The user will enter a value for each parameter relating to each storm segment including the associated inter-event period, if applicable. When using multiple events, the user must be aware of the timing of the complex storm. Hydrograph durations are determined by the combined input of number of points in the hydrograph and the hyrograph time step. Likewise the inter-event durations are determined by the combined input of number of points in the inter-event and the inter-event time step. The duration of the rainfall event, which is implicity entered in the rainfall data block, |must also be coordinated with the data entry of the time parameters in this data block such that hydrograph durations are compatible. Dry weather removal parameters also include timing. Because of the needed orchestration of all time related parameters in the model, it is recommended that the layout of a complex storm time line be used to assist in defining the values of these parameters.

Variable	Description
KWTI	**Kinematic Wave Time Interval (minutes). This is the computation time interval for the kinematic wave runoff routine and is constant for all runoff compututations assocaited to all rainfall segment. This parameter is entered only once by the user. It is important to realize that HYDTI and RFTI must be integral multiples of KWTI.**
HYDTI	**HYDrograph print Time Interval (minutes). Runoff rates and pollutant concentrations will be displayed at this time interval in the output. Select this parameter based upon the length of the associated storm and the parameter HYDNPT. This parameter is entered only once and is used for printout off all hydrograph segment(s).**

RFTI — **RainFall Time Interval** (minutes). The rainfall hyetograph will be defined in rainfall amounts over this time interval. During observed rainfall input, the user will enter **NPT** rainfall amounts occurring over this time interval. For synthetic rainfall, the rainfall routines will compute the rainfall amounts occurring over this time interval base upon the chosen distribution. At this time in the evolution of PSRM-QUAL, the user must enter **RFTI** equal to **HYDTI**. It is hoped that later versions will relax this restriction.

IETI — **InterEvent Time Interval** (minutes). This is the printing time interval for all output ordinates generated during the inter-event segments and is typically much larger than its associated hydrograph segment print interval of **HYDTI**. This interval must be an integral multiple of **HYDTI**. If NST = 1, the program automatically sets this parameter to 0. **IETI** must be at least twice the magnitude of **HYDTI**. Otherwise the program may not run properly.

HYDNPT — **Hydgrograph Number of PoinTs.** Every hydrograph segment duration is defined by the combined input of this parameter and **HYDTI**. To get reasonable output from the model, this number should be set in coordination with the associated storm **RFNPT**. The duration of the hydrograph should be at least twice the duration of the rainfall event. Keep in mind that RFTI and **HYDTI** are equal in this model.

IENPT — **Inter-Event Number of PoinTs.** Similar to hydrograph segment durations, inter-event segment durations are defined by the combined input of this parameter and **IETI**. It is assumed that inter-event periods are of longer duration than hydrograph periods.

MaxHNPT — **Maximum Hydrograph Number of PoinTs.** This parameter does not appear for input in the "File Create" routine, but it is placed in the INP file for use by PSRM-QUAL. This is the maximum number of points in a hydrograph, considering multiple storms, for the complete analysis. This parameter is used to dimension certain rainfall and runoff arrays in XOPT3.EXE. The user may need to adjust this parameter if using EDIT to change the value of **HYDNPT** of any storm in an INP file.

TotNPT | **Total Number of PoinTs.** This parameter does not appear for input in the "File Create" routine, but it is placed in the INP file for use by PSRM-QUAL. This is the sum of all **HYDNPT** and **IENPT** for all storms in the analysis.

6.4 Rainfall Parameters

The input required for this block of data is dependent upon the value of **STOPT**. Each storm option requires its own specific data.

6.4.0 STOPT = 0: Observed Rainfall (manual entry of a hyetograph)

Observed rainfall requires rainfall increment data for at least one recording rain gage. When more than one recording rain gage is used in the analysis, the program conserves the pattern of the gage closest to the centroid of the subarea under analysis. Rainfall amounts of other recording gages are used to scale the pattern according to the weighting scheme. Non-recording (total rain) gages can also be used. The total rain from the non-recording gages is distributed according to the preserved distribution of the closest recording gage. Several gages area allowed by the program. One set of rainfall data must be entered for each gage during every storm segment. This storm option can also be used to manually enter design storm hyetographs.

6.4.0.1 Rain Gage Parameters

Variables	Description
NRG	**Number of Recording Gages.** This parameter must be at least 1 if **STOPT** = 0. At this time the maximum number of raingages has no program limit.
NNRG	**Number of Non-Recording Gages.** The value of this parameter may be 0 or greater. Non-recording gages are also referred to as total rain gages.
NWG	**Number of Weighting Gages.** For each subarea runoff computation, the program will select the NWG closest gages to the centroid of the subarea to establish the weighted rainfall distribution. This parameter must not be less than 1 and cannot exceed the sum of **NRG** and **NNRG**. If this parameter is

set to 1, then no rain gage weighting is performed; the program uses the closest recording raingage to the subarea centroid. If weighting of rain gage data is desired, then NWG must be greater than 1.

EXW EXponent for Weighting. This is the exponent, m, for hyetograph inverse distance weighting routine. The recommended value for EXW is 2.

6.4.0.2 Recording Rain Gage Parameters

Variables	Description
RGNAME$	Rain Gage NAME. The name of the rain gage can be up to twenty characters in length and is entered only once per gage. During successive storm event data input the rain gage name is displayed but is not available for edit.
XRG	X coordinate of Rain Gage. The relative X (Y for YRG) position of the rain gage location with respect to some reference point in the proximity of the watershed. This reference point must be the same reference point used to establish XCG and YCG of the subareas. The length unit of this parameter is up to the user but it must be consistent with the coordinate length unit of other coordinates (XCG and YCG). The magnitude must be an integer value between -9999 and 9999. For successive storm segment data input, the coordinate data is displayed but is not available for edit.
YRG	Y coordinate of Rain Gage. See XRG.
RFNPT	Number of rainfall PoinTs. This number in conjunction with RFTI determines the duration of the rainfall event. Note that the storm segment length (RFNPT * RFTI) should be significantly shorter than the associated hydrograph duration. Note that the File Create routine writes rainfall amounts in groups of six per data line in the INP file. This structure should be maintained when changing the contents of an INP file using a text editor.
RGST	Rain Gage Start Time (minutes). This is the time, relative to the storm event start time, when the rain gage starts recording. This parameter reflects the

variation of rainfall recording start times from one gage to another for the same storm segment.

6.4.0.3 Non-Recording Rain Gage Parameters

Variables	Description
RGNAME$	Rain Gage NAME. See the description of RGNAME$ for recording rain gages in the previous section.
XRG	X coordinate of Rain Gage. See XRG of recording rain gages in the previous section.
YRG	Y coordinate of Rain Gage. See YRG of recording rain gages in the previous section.
RFDPTH	RainFall DePTH (inches). This is the total depth of recorded rainfall at this gage for the specific storm segment.

6.4.1 STOPT = 1: Synthetic Rainfall: PDT IDF curves.

Variables	Description
REGION	Pennsylvania storm REGION. Storm region must be a value of 1 to 5 and can be determined based upon geographic location of the watershed as defined in the PDT-IDF publication.
RETPRD	RETurn PeRioD of the storm. The user must enter one of the seven return periods (1, 2, 5, 10, 25, 50, 100) available in the PDT-IDF document.
RFNPT	Number of rainfall PoinTs. The synthetic hyetograph will have RFNPT discrete rainfall amounts. This parameter, along with RFTI, will determine the duration of the rainfall event.

6.4.2 STOPT = 2: Synthetic Rainfall: SCS Type I, II, III

Variables	Description
RFDIST	RainFall DISTribution. The user must enter the desired SCS rainfall distribution for the synthetic storm.(I = 1, II = 2, III = 3).
RFNPT	Number of rainfall PoinTs. The synthetic hyetograph will have **RFNPT** discrete rainfall amounts. This parameter, along with **RFTI**, will determine the duration of the rainfall segment.
RFDPTH	RainFall DePTH (inches). This is the 24 hour rainfall depth for the rainfall distribution defined by RFDIST. This parameter is used to create a scaled storm segment with duration RFNPT * RFTI. The user must enter the 24 hour rainfall depth regardless of the actual duration of the storm. For Pennsylvania storms, the PDT-IDF curves provide this information. The rainfall maps in the appendix of the SCS publication *TR-55 Urban Hydrology for Small Watersheds* also provide national rainfall data.

6.4.3 STOPT = 3: Synthetic Rainfall: USWB IDF curves (Yarnell equations).

Variables	Description
RFNPT	RainFall Number of PoinTs. The synthetic hyetograph will have **RFNPT** discrete rainfall amounts. This parameter, along with **RFTI**, will determine the duration of the rainfall event.
RFDPTH	RainFall DePTH (inches). This is the associated 1 hour rainfall depth for the storm segment of interest (usually defined by return period). This parameter is used to create a scaled storm with duration RFNPT * RFTI. The user must enter the 1 hour rainfall depth regardless of the actual duration of the storm. For Pennsylvania storms, the PDT-IDF curves provide this information. The rainfall maps in the appendix of the SCS publication *TR-55 Urban Hydrology for Small Watersheds* provide national rainfall data.

6.5 Standard Subarea and Drainage Element Parameters

The standard parameter block is provided to reduce the required data input effort for subarea and drainage element parameters. Twenty five parameters have been identified as having the potential for similar values at other locations across the watershed. The program will offer these standard parameter values as default input for each subarea. The user may edit or simply accept them. The supporting data file STDPARAM.DAT contains the values of the standard "default" parameters that the file create routine reads and offers to the user. The user may modify the content of this file by using any text editor to change specific values. See Appendix "A", "Changing the Contents of a DAT File".

6.5.1 Overland Routing and Channel Routing

Variable	Description
STDMN1	STanDard Manning's N value for impervious areas. This is an overland flow roughness parameter and is used in the kinematic wave runoff routine for impervious areas in each subarea.
STDMN2	STanDard Manning's N value for pervious areas. This is the same parameter as STDMN2 except for pervious areas. A suggested range of this parameter is 0.2 to 0.4.
STDSF	STanDard Sinuosity Factor. This parameter is used to adjust for overland flow length due to surface undulation in the flow path. The program will multiply the flow LENGth of each subarea by this value and also divide the SLOPE of each subarea by this factor.
STDMX	STanDard Muskingum X coefficient. Also referred to as the weighting factor or wedge coefficient, X, this parameter reflects the relative significance of inflow and outflow of the reach to determine reach storage. The mathematical range is 0 to 0.5. If X = 0 the channel reach acts like a detention storage facility, and storage is completely a function of outflow. If X = 0.5 the reach has no storage capacity and routing only translates the hydrograph through the reach travel time. Most natural streams have an X

value of around 0.2 to 0.3. Regular channels and pipes have X values around 0.4 to 0.5.

STDCTS STanDard Channel To Surface velocity ratio. This is the ratio of inbank to overbank flow velocities. It is used to increase the travel time of surcharge flow and has been found to be a very useful model calibration parameter.

6.5.2 Rainfall Losses

Variable	Description
STDCN1	STanDard Curve Number for impervious areas. Used in the modified SCS runoff relation, this parameter should range between 95 and 99.
STDCN2	STanDard Curve Numbers for pervious areas. Used in the modified SCS runoff relation for pervious areas, this parameter has a practical range of 55 to 90 and is based upon hydrologic soil group and landuse.
STDIAF	STanDard Initial Abstraction Factor. This is the value of the coefficient "c" used to determine initial abstraction, IA, as it relates to soil storage capacity, S_c ($IA = c\ S_c$). The Soil Conservation Service recommends a value of 0.2* for this initial abstration factor. Independent studies at Penn State have indicated that for urban areas a more reasonable value may range between 0.05 and 0.2. When assigning the value of this parameter, the user should also consider the values for depression storage. In the SCS development of their runoff relation, initial abstraction includes the effect of depression storage.

*NOTE: The Soil Conservation Service does not recommend the variation of this factor from it's originally established value of 0.2. Their reasoning is that all curve number values available in SCS publications were established for the condition of $IA = 0.2\ S_c$, and to use these curve numbers under any other initial abstraction condition would be a mis-match in data input. Penn State University recognizes this claim as legitimate. However, in the interest of model calibration the "illegitimate" adjustment of this factor has been found useful.

STDDS1 STanDard Depression Storage for impervious areas (inches). This parameter is offered to the user to increase flexibility in determining rainfall losses. In general, depression storage is considered to be part of the initial abstraction determined in the SCS runoff relation. However, in impervious areas, soil storage capacity, S_c, in the SCS curve number relation will almost always be less than 0.5 inches. If the intitial abstraction factor (IAF) is 0.05, then initial abstraction (IA) probably does not include the pavement depression storage. A value for pavement depression storage in urban areas has been suggested by Lindsley [*reference unknown*] as approximately 1/16 of an inch (0.06 inches). This value may also include any minor loss that the user feels must be considered and is better represented by a constant depth.

STDDS2 STanDard Depression Storage for pervious areas (inches). In most cases, initial abstraction will account for this parameter on pervious surfaces since pervious surface curve numbers are typically low (as compared to impervious areas). This value may also include any minor losses that the user feels must be considered and is better represented by a constant depth.

STDKS STanDard saturated hydraulic conductivity, KS (inches/hour) The saturated hydraulic conductivity of the soil is used to estimate the equilibrium infiltration capacity of the soil. Recommended values of KS are shown in Table 3.2.

STDIFSW STanDard Initial Fraction of Soil capacity Wetted. The range of this parameter varies from 0 for completely dry conditions to 1 for saturated conditions.

6.5.3 Land Use and Impervious Area Sediment Loading

<u>Variable</u> <u>Description</u>

STDLU √ STanDard Land Use index. The land use parameter range is 0 to 4 and reflect the following land use conditions

1 - Residential,
2 - Mixed residential and commercial,
3 - Commercial,
4 - Open/Non-urban.

The parameter is used to select the appropriate pollutant concentration factors from the data file POLC.DAT.

STDMSL STanDard Maximum Sediment Load (grams/curb meter). This parameter is used for the impervious areas an upper limit to sediment build-up during the inter-event periods. Recommended values can be found in Table 4.5.

STDISL STanDard Initial Sediment Load (grams/curb-meter). Also used in the inter-event pollutant build-up routine, this is the sediment load at the beginning of the first rainfall event.

STDSWST STanDard SWeeping Start Time (hours). This is the time when the first street sweeping activity occurs after the beginning of the analysis. If no street sweeping activities occur in the watershed , set this parameter to 0.

STDSWTI STanDard SWeeping Time Interval (days). This is the time interval between street sweeping activities in the urban area. If no street sweeping activities occur in the watershed , set this parameter to 0.

STDSWFR STanDard SWeeping Fraction Removed. This is the average fraction (0 to 1) of surface sediments removed during the street sweeping operation. If no street sweeping activities occur in the watershed , set this parameter to 0.

6.5.4 Pervious Area Sediment Loading

Variable	Description
STDUK	STanDard Universal soil loss equation K factor. This is the USLE soil erodability factor and is based upon soil texture and soil organic content. It has a mathematical range of 0 to 1 and a practical range of 0.02 to about 0.6. Refer to Table 4.7
STDUC	STanDard Universal soil loss equation C factor. This is the USLE cropping management factor and is based upon land use and land cover. The practical range of UC is 0 to 1. Refer to Table 4.8.
STDUP	STanDard Universal soil loss equation P factor. This is the USLE erosion control practice factor and has a practical limit of 0.1 to about 1.3. Refer to Tables 4.9 and 4.10.

6.5.5 Sediment Dislodging and Wash-off

Variable	Description
STDSBK	STanDard Sartor-Boyd K value (1/inch). This parameter is the soil particle dislodging coefficient for impervious areas and is equivalent to the Sartor-Boyd dislodging proportionality constant K.
STDCD	STanDard Coefficient of Drag. This is the drag coefficient acting on sediment particles in the surface runoff. In the program, one coefficient is used for all sediment particle sizes.
STDDFC	STanDard Dynamic Friction Coefficient. This is the friction coefficient used on soil particles that are already in motion. DFC is always less than SFC.
STDSFC	STanDard Static Friction Coefficient. This is the friction coefficient that is used on particles that are resisting initial movement (incipient motion). SFC is always greater than DFC.

6.6 Subarea Parameters

Twenty three of the twenty five standard parameters are defined as subarea-related parameters. Eight additional parameters are required for input to each subarea data set. The user will be prompted to input the non-standard parameters. The standard parameters will be automatically presented for edit or acceptance. The subarea parameters are divided into six logical groups, namely: (1) Geometry, (2) Overland Flow Routing, (3) Rainfall Losses, (4) Landuse and Impervious Sediment Loading, (5) Pervious Sediment Loading and (6) Sediment Dislodging and Wash-Off. If the quality mode is not invoked, then data groups 4, 5 and 6 are not offered for data entry.

6.6.1 Geometry

Variable	Description
XCG	X coordinate of the subarea "Center of Gravity". The X (Y for YCG) position of the geographic center of the subarea with respect to some reference point

in the proximity of the watershed. This reference point must be the same reference point used to establish **XRG** and **YRG** of the rain gages. The units of this parameter are arbitrary and the magnitude must be between -9999 and 9999. This coordinate information is used to weight observed rainfall for the individual subareas.

YCG Y coordinate of the subarea "Center of Gravity". See **XCG**.

AREA **AREA** (acres). This is the surface area of the subarea.

LENG **LENGth of the characteristic flow path** (feet). This length should be representative of the average flow path length for the subarea. It is used in the kinematic wave runoff routine and is typically scaled from a map. The parameter **SF** can be used to alter this **LENGth** within the program. See the description of **SF (STDSF)** under the standard parameters block.

SLOPE **SLOPE of the characteristic flow path** (ft/ft). This slope should be representative of the average flow path slope for the subarea. It is used in the kinematic wave runoff routine. Typically, this can be determined by dividing the average flow path length by an average elevation drop across the subarea. The parameter **SF** can be used to alter this **SLOPE** within the program. See the description of **SF (STDSF)** under the standard parameters block.

FRIMP **Fraction of area IMPervious.** This parameter must range between 0 and 1 and is an estimate of the amount of surface area defined by **AREA** that is impervious. This value can be estimated from observing land use within the subarea or more rigorously determined by examination of land use maps or aerial photographs if available.

6.6.2 Overland Flow Routing

<u>Variable</u> <u>Description</u>

MN1 **Manning's N value for impervious areas.** See **STDMN1** in the standard parameters data block, section 6.5.

MN2	Manning's N value for pervious areas. See STDMN2 in the standard parameters data block, section 6.5.
SF	Sinuosity Factor. See STDSF in the standard parameters data block, section 6.5.

6.6.3 Rainfall Losses

Variable	Description
CN1	Curve Number for impervious areas. See STDCN1 in the standard parameters data block, section 6.5.
CN2	Curve Numbers for pervious areas. See STDCN2 in the standard parameters data block, section 6.5.
IAF	Initial Abstraction Factor. See STDIAF in the standard parameters data block, section 6.5.
DS1	Depression Storage for impervious areas (inches). See STDDS1 in the standard parameters data block, section 6.5.
DS2	Depression Storage for pervious areas (inches). See STDDS2 in the standard parameters data block, section 6.5.
KS	Saturated hydraulic conductivity, KS (inches/hour). See STDKS in the standard parameters data block, section 6.5.
IFSW	Initial Fraction of Soil capacity Wetted. See STDIFSW in the standard parameters data block, section 6.5.

6.6.4 Land Use and Impervious Area Sediment Loading

Variable	Description
LU	Land Use. See STDLU in the standard parameters data block, section 6.5.

MSL	Maximum Sediment Load (grams/curb meter). See STDMSL in the standard parameters data block, section 6.5.
ISL	Initial Sediment Load (grams/curb-meter). See STDISL in the standard parameters data block, section 6.5.
SWST	SWeeping Start Time (hours). See STDSWST in the standard parameters data block, section 6.5.
SWTI	SWeeping Time Interval (days). See STDSWTI in the standard parameters data block, section 6.5.
SWFR	SWeeping Fraction Removed. See STDSWFR in the standard parameters data block, section 6.5.

6.6.5 Pervious Sediment Loading; Sediment Dislodging and Washoff

Variable	Description
UK	Universal soil loss equation K factor. See STDUK in the standard parameters data block, section 6.5.
UC	Universal soil loss equation C factor. See STDUC in the standard parameters data block, section 6.5.
UP	Universal soil loss equation P factor. See STDUP in the standard parameters data block, section 6.5.
SBK	Sartor-Boyd K value (1/inch). See STDSBK in the standard parameters data block, section 6.5.
CD	Coefficient of Drag. See STDCD in the standard parameters data block, section 6.5.
DFC	Dynamic Friction Coefficient. See STDDFC in the standard parameters data block, section 6.5.

SFC	**Static Friction Coefficient.** See **STDSFC** in the standard parameters data block, section 6.5.

6.7 Organic Compounds

The user has the option of modeling one or two trace organic materials if the quality routine is used. The parameter NORG, entered in the watershed elements data block, must be set to 1 or 2 for this routine to be made available to the user. The routine assumes that the mass of organic materials in each particle size range is directly proportional to that of volatile solids.

Variable	Description
ORGNAME$	**ORGanic NAME.** This can be any descriptive name for the trace organic, up to eight characters long. This name will appear in the INP file with it's full eight characters. In the headings of the OUT file, this name will be trimmed to five characters.
ORGCONC	**ORGanic CONCentration** (micrograms/gram of total solids of sediment). This parameter works in a fashion similar to the pollutant concentration factors found in POLC.DAT. Suggested values for this parameter in urban areas are shown in Table 4.11.

6.8 Drainage Element Parameters

Every subarea has an associated drainage element and possibly associated connecting drainage element(s). These drainage elements may be swales, open channels or storm sewers. The user must estimate the full flow capacity and full flow travel time of each drainage element. Connecting upstream drainage elements for each subarea must be identified.

Variable	Description
CAP	**CAPacity of the drainage element** (cfs). Estimate this parameter by considering the element under full flow conditions

PT Pipe or channel travel Time (minutes). This is the drainage element travel time under full flow conditions and it is used in the Muskingum channel routing routine to estimate the proportionality coefficient, K.

MX Muskingum X coefficient. See STDMX in the standard parameters data block, section 6.5.

CTS Channel To Surface velocity ratio. See STDCTS in the standard parameters data block, section 6.5.

NCDE Number of Connecting Drainage Elements. This is the number of CDEs that are associated with the drainage element. This number can range from 0 to 3. See the following description of CDE.

CDE Connecting Drainage Element. This is the drainage element identification number of an upstream drainage element that is contributing runoff to the current drainage element. The program allows up to three connecting drainage elements per drainage element. The input routine refers to these parameters as CDE1, CDE2 and CDE3.

6.9 Reservoir Parameters

Any subarea within the watershed may contain a reservoir. All reservoirs require the input of an elevation-storage-outflow (ESO) table. The user will be asked for each elevation (**Elev**), and its associated storage (**Stor**) and outflow (**Flow**) in an editable data entry window.

Variable Description

SArea Reservoir SubArea identification. This parameter identifies the subarea in which the reservoir exists. This parameter is used by the program to keep track of reservoir data when two or more reservoirs exist in a watershed. This number is actually entered by the user in the watershed elements data block. It is presented as a reference for the user during reservoir data input on the first line of the computer screen.

RTYP	**Reservoir TYPe.** Reservoirs can be treated as local to the subarea or global to the watershed. If **RTYP** is set to 1, then the reservoir is local to the subarea and only handles the runoff generated within that subarea. If RTYP is set to 2, then the reservoir is located in the major drainage element of that subarea and handles all runoff from all subareas above that drainage point.
QBYP	**Flow (Q) BY-Pass** (cfs). Reservoirs can contain a flow by-pass structure to pass the event's early runoff around or through the reservoir. This feature can be used to minimize the storage volume requirements of the reservoir.
NESO	**Number of Elevation-Storage-Outflow points.** This parameter determines the size of the ESO table for the reservoir. Up to twelve data points can be entered. In addition to storage calculations, the program uses the ESO table to determine pond depth for the BMP routines. Therefore, the first ESO point must be the bottom elevation of the reservoir with storage and outflow set to zero. When entering **NESO**, be sure to include this bottom elevation point in the number.
IWSE	**Initial Water Surface Elevation.** The user may specify an initial water surface elevation in the reservoir if the reservoir is partially filled at the beginning of the event. Please note that **IWSE** and the first elevation point in the ESO table are not necessarily the same.
Elev, Stor, Flow	These are the values of the ESO table. The first **Elev** point must correspond to the reservoir (or BMP) bottom elevation where storage and outflow are zero.

6.10 BMP Parameters

In general, BMP parameters are keyed to BMP sediment removal mechanisms. Certain sediment removal mechanisms are then assigned to a specific BMP based upon **BTYP** and **REMOPT**. Therefore, only a subset of the following parameters will be entered by the user for a given BMP.

6.10.1 General BMP Parameters

Variable	Description
SArea	BMP SubArea identification. This parameter identifies the subarea in which the BMP exists. This parameter is used by the program to keep track of BMP data when two or more BMP exists in a watershed. This number is actually entered by the user in the watershed elements data block. It is presented as a reference for the user during BMP data input on the first line of the computer screen.
BTYP	**Bmp TYPe**. This number has a valid range of 1 to 6 and is referenced as follows: 1 = Dry Detention Basin (DDB) 2 = Dry Extended Detention Basin (DXDB) 3 = Wet Detention Basin (WDB) 4 = Constructed Wetlands (CW) 5 = Infiltration Basin (IB) 6 = Infiltration Trench (IT)
REMOPT	**REMoval OPTion**. The user is offered at least two pollutant removal options for a specific BMP type. Every BMP offers a "Level 1" removal option. "Level 1" options utilize a simplified removal routine, also referred to the default routine. For BMP types 1 through 4, the default option is a simple percent removal of suspended sediment which is applied to every inflow ordinate. For BMP types 5 and 6 (infiltration facilities), the default option uses a simple constant infiltration rate (**MINRATE**), and removal is computed based upon mass balance. Default removal rates for BMP types 1 through 4 as a function of pollutant type are defined in the data file REMRATES.DAT. The user may change the content of this file by using any simple text editor. See Appendix A: Changing the Content of a DAT File. In addition to the contents of this file, most BMP routines require the entry of an ESO table to accomodate complete hydraulic routing of the flood wave through the facility.

"Level 2" removal options are also available and require more parameter input than an ESO table. Table 5.1 indicates the removal mechanisms associated to the BTYPs at "Level 2". For BMP types 5 and 6, the parameter REMOPT is automatically set equal to 2 when falling head and infiltration data are entered.

6.10.2 Grass Filtration

This mechanism assumes vegetation on the floor of a dry basin or constructed wetland is available to act like a vegetated buffer zone for filtration of sediments. The mechanism is terminated once water depths in the basin are above the vegetation height or above the first stage vertical flow dimension of the BMP outlet structure, which ever is smaller.

Variable	Description
GRSPCG	Grass SPaCinG of the BMP bottom (inches). This is the average spacing between grass blades on the bottom of the BMP. This parameter is used to compute a hydraulic radius of the shallow flow through the basin bottom during periods when filtration is applicable. In turn this hydraulic radius is used to compute the velocity of flow through the vegetation.
GRHGT	GRass HeiGhT of BMP bottom (inches). This is the average height of vegetation on the basin bottom and is also used to compute the hydraulic radius as mentioned in the description of GRSPCG.
STGDIM	STaGe DIMension (inches). This is the characteristic depth dimension of the first stage of the BMP outlet structure. The smaller of this parameter and GRHGT is used to establish the pond depth where the filtration removal mechanism ends and the settling mechanism begins.

6.10.3 Sedimentation

This mechanism estimates sediment removal due to setting in the detention facility water column.

Variable	Description
BOTEL	**BOT**tom **El**evation of basin (feet). The elevation of the bottom of the basin is used in the settling routine to determine the height of the settling column, also known as pond depth. This parameter should not to be confused with **IWSE** of the elevation-storage-outflow routine. **BOTEL** is the elevation of the bottom of the basin and is equivalent to **Elev(1)** in the ESO matrix (see section 6.9.1). **IWSE** is the elevation of the wet pool prior to the storm event.
SCN	**S**hort **C**ircuiting **N**umber. The short circuiting number can range from 1 to infinity and is an indicator of turbulence and short circuiting in the basin. When **SCN** = 1 the basin has the poorest setting capability as affected by turbulence and short circuiting. When **SCN** = ∞ the basin has ideal setting characteristics with respect to turbulence and short circuiting. The program allows a practical limit of 100 for **SCN**. There is no noticeable difference in basin performance between **SCN** = 100 and **SCN** = ∞.

6.10.4 Resuspension

This mechanism adds sediment load to the stored runoff in the BMP. It assumes that accumulated sediments from previous events are available in the basin of the BMP for resuspension.

Variable	Description
BOTSLP	**BOT**tom (friction) **SL**o**P**e (ft/ft). This slope parameter is used to compute the bottom velocity in the BMP during all time steps of the removal process, except when filtration is used as a removal mechanism. Bottom velocities are in turn used to compute resuspension volumes. The user should keep in mind that this is truly a friction slope and not a bottom slope.
BOTEFL	**BOT**tom **EF**fective **L**ength (feet). This parameter is used in conjuction with pond depth and storage volume to estimate a pond width for a given time step. This width is used to assist in the computation of the bottom velocity of the BMP.

BOTMN	BOTtom Manning's N value. This parameter is used to assist in the computation of bottom velocity for the BMP.

VBOTSED	Volume of BOTtom SEDiments (cuft). This is the estimated volume of sediments which is available for resuspension in the bottom of the BMP prior to the first storm event. This may be estimated as a percentage of the total runoff storage volume of the BMP. Reasonable percentages might range anywhere from 0 to 10 percent, depending upon the BMP age and maintenance.

6.10.5 Constructed Wetlands Kinematic Wave

The first three parameters in this data block are identical to those defined in the resuspension routine, but are applied to the kinematic wave routine for flow through a wetland. If the user options to run a quality file in the no-quality mode, the program still needs these parameters for runoff routing through the wetlands. These special parameters have been defined for the wetland to accommodate the separate runoff and quality routines in the program.

Variable	Description
CWBSLP	Constructed Wetland Bottom (friction) SLoPe (ft/ft). This parameter defines the flow through friction slope of the wetlands.
CWBEFL	Constructed Wetland Bottom EFfective Length (feet). The number of cascade computation lengths through the wetland is determined from this parameter along with the internally computed flow through travel time of the wetland.
CWBMN	Constructed Wetland Bottom Manning's N. The bottom roughess coeficient should be chosen with care. If the average flow through depth is shallow with vegetation providing the majority of the flow resistence, then "n" should be treated as a sheet flow roughness instead of a channel flow roughness.

CWYINI — Constructed Wetland (Y) INItial depth of flow (feet). This parameter establishes the initial condition of flow depth in the wetlands for time equals zero.

CWWDTH — Constructed Wetland characteristic WiDTH (feet). This parameter is used to compute total flowrate through the wetland. The kinematic wave routine computes flow in cfs/ft.

6.10.6 Infiltration Facilities

Infiltration basins can be either trapezoidal or circular in geometry. Depending on the geometry, the input requirements will vary. Both basin geometries require the input of a head-infiltration table or a default minimum infiltration rate. Infiltration trenches can only be trapezoidal, with the rectangular trench being a special case of the trapezoidal shape.

Variable	Description
IFGEOM	Infiltration Facility GEOMetry. If the basin is trapezoidal in shape this parameter is set to 1. For circular basins, this parameter is set to 2.

6.10.6.1 Trapezoidal Geometry

Variable	Description
IFBWDTH	Infiltration Facility Bottom WiDTH (feet). This parameter is used to compute the volume of storage of the infiltration facility for a given depth. It is also used in the calculation of the exfiltration outflow of the facility.
IFBLEN	Infiltration Facility Bottom LENgth (feet). This geometry parameter is used in a similar fashion as IFBWDTH.
IFDPTH	Infiltration Facility DePTH (feet). This depth is used to compute the basin full capacity of the facility. The full storage volume defines the storage point where pollutants are discharged to the downstream channel via overflow.

IFHSS Infiltration Facility Horizontal component of Side Slopes. (ft/ft) This parameter replaces the α term in the exfiltration overflow equations of sections 5.7.5 and 5.7.6.

IFRF Infiltration Facility Reduction Factor. This factor is used to scale up or down the values of infiltration in the falling head vs. depth table entered by the user. This parameter can be used to examine the effects of clogging on the effectiveness of the facility.

IFPOR Infiltration Facility PORosity. Porosity is entered only for the infiltration trench facility and is used to estimate trench water depth based on storage volume computed in the routing routine.

6.10.6.2 Conical Geometry

<u>Variable</u> <u>Description</u>

IFBDIA Infiltration Facility Bottom Diameter (feet). This facility diameter defines the basin bottom radius and is used to compute the basin full water surface radius, need to compute exfiltration outflow for basin full conditions.

6.10.6.3 Head-Infiltration Table

<u>Variable</u> <u>Description</u>

NFHP Number of Falling Head Points. This parameter determines the size of the head-infiltration table for the infiltration facility. The program allows up to ten points in any head-infiltration table. The first falling head point must be depth of 0 and infiltration of 0. The data input routine will automatically set this first point to 0,0. Therefore if the user enters 6 as NFHP, the user can only enter five points other than 0,0 in the table.

MINRATE MINimum infiltration RATE (in/hr). This parameter is an optional default value for estimating the infiltration capacity of an infiltration facility when field data is not available. This parameter is a constant value for all points, not changing with water depth.

HEAD Falling **HEAD** (feet). These are measured field data points for which associated infiltration rates are recorded.

INFIL **INFIL**tration rate (in/hr). The user must enter the appropriate number of design inflitration data points to define the H-I table for the infiltration facility. This data is usually a percentage of the observed rates to account for lost infiltration capacity of the facility with time.This is the design infiltration rates determined from

6.10.7 Decay of Dissolved Species

There are no specific inputs for this removal routine, however the content of the file DECAY.DAT is used to establish the values of the decay rates for each pollutant. The user may change the content of this file by using any simple text editor. See Appendix A: Changing the Content of a DAT File.

6.11 Observed or Inflow Hydrograph Parameters

Any subarea within the watershed may contain an observed or inflow hydrograph. The parameter **NOBS** in the watershed element data block must be greater than zero if the user wishes to use this option. The user will be asked for specific data on each hydrograph, and the associated flows (**Flow**) will be entered in an editable data entry window.

Variable	Description
SArea	**SubArea** identification number.
HTYP	**H**ydrograph **TYP**e. This is the hydrograph type index. If **HTYP** = 0 then the hydrograph is observed. If **HTYP** = 1 then the hydrograph is inflow. Negative inflow values can be used for subarea diversions.
NOHO	**N**umber **o**f **H**ydrograph **O**rdinates. This parameter determines the number of flow values that the file create routine will accept through the data entry window. A practical maximum of 99 has been set for this parameter.

HTSL Hydrograph Total Sediment Load (pounds). If the INP file being created is a quality file, then the user will be asked to provide an estimate of the total sediment load included in the inflow hydrograph. If the user enters 0 here, then the program assigns a sediment load to the inflow hydrograph which is proportional to the sediment load of the hydrograph to which it is added. This parameter is not entered for a quantity only INP file.

OHLU Observed Hydrograph Land Use. For INP files that contain quality data, this parameter indicates the land use associated with the incoming observed hydrograph. This parameter is used to associate the pollutant association factors of POLC.DAT to the sediments in the observed hydrograph.

Flow Observed flows or inflows. These values will be entered through a data entry window. NOHO values will be entered. Positive flow values indicate inflow to the subarea. Negative flow values indicate diversion.

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APPENDIX A: Changing the Content of a DAT File

The contents of the supporting DAT files should be examined closely and changed to match the characteristics of the watershed under analysis prior to application of the model. Listings of each DAT file as originally provided with the software are shown at the end of this section. The procedure for changing the content of a DAT file is quite simple as long as attention is paid to the number of data items per row and the position of the text lines. The files can be modified by using any text editor, as long as the DAT files are saved as text readable (ASCII) files. The MS-DOS program EDIT is very convenient for editing the contents of these files and can be accessed directly from the PSRM-QUAL main menu.

The DAT files used in PSRM-QUAL are read sequentially (vs. random access) and must maintain a very specific structure. All DAT files contain two types of lines; text lines and data lines. Text lines provide information to identify the file contents and are solely for the convenience of the user. These lines are read by the program but disregarded in terms of content. Even though text lines do not contain any useful information to the program, the data file read routines expect text lines and data lines to appear in a very specific order. When this order is violated, the file will not be read properly or not at all. Data lines contain numerical values used by PSRM-QUAL to make calculations. These values must be placed in the file in a specific order and separated by delimiters to make certain the file is read properly.

Data items are separated in a number of ways, but mainly by the delimiters of (1) a carriage return (end of a line), [2] a comma with or without trailing spaces, [3] a single space or [4] a group of spaces. Any of these delimiters can be used to separate data in a DAT file. It is worth noting that text lines do not use the space or group of spaces as a delimiter. However they do use the carriage return and the comma, ***so be careful to not enter a comma on a text line.***

Consider the file DECAY.DAT which consists of six lines total. Four of these lines are text lines and two of these lines are data lines. The program could just as easily read the following file forms and get the same information.

DECAY.DAT alternate form 1

```
Text
Any text
More of any text with at least one character but no commas!
-0.06, -0.01, -0.15, -0.01, -0.20, -0.20
A
0.33, 1.00, 0.15, 1.00, 1.00, 1.00
```

DECAY.DAT alternate form 2

```
text
text
text
-0.06
-0.01
-0.15
-0.01
-0.20
-0.20
A
0.33
1
0.15
1
1
1
```

DECAY.DAT alternate form 3

```
text,text,text,-0.06,-0.01,-0.15,-0.01,-0.20,-0.20,text,0.33,1,0.15,1,1,1
```

Thus DECAY.DAT must contain sixteen items in the following order: three text items, six data items, one text item and six data items, all separated by an appropriate delimiter.

Although the form of the DAT files can be change significantly, it is suggested that the original form of the files be maintained as closely as possible. Users may wish to create back-up copies of the original DAT files for later reference.

LISTING OF THE DAT FILES AS ISSUED WITH PSRM-QUAL

DECAY.DAT: Pollutant BMP Decay Factors for PSRM-QUAL

Pollutant decay coefficients in 1/days

TKN	NO2+NO3	TP	SP	COD	BOD
-0.06	-0.01	-0.15	-0.01	-0.20	-0.20

Dissolved fractions

TKN	NO2+NO3	TP	SP	COD	BOD
0.33	1.00	0.15	1.00	1.00	1.00

POLC.DAT: Pollutant Factors for PSRM-QUAL

Pollutant Concentration Factors in g/100g of TSS

	Cu	Zn	Pb	TKN	NO2+3	TP	SP	COD	BOD
Residential	0.0327	0.134	0.143	1.88	0.729	0.379	0.142	72.3	9.9
Mixed	0.0403	0.230	0.170	1.93	0.833	0.393	0.084	97.0	11.6
Commercial	0.0420	0.328	0.151	1.71	0.829	0.291	0.116	82.6	13.5
Open/NonUrban	0.01	0.279	0.043	1.38	0.776	0.173	0.037	57.1	7.9

Pollutant Loading Factors

	curb-meters/hectare	build-up exponent
Residential	385	0.2
Mixed	385	0.2
Commercial	385	0.2
Open/NonUrban	385	0.2

PSDIST.DAT: Particle Size Distributions for PSRM-QUAL

GrainSize ID Numbers for 13 groups of sediments

0 1 2 3 4 5 6 7 8 9 10 11 12 13

GrainSize (microns)

4800 2000 840 250 105 74 65 55 45 35 25 15 5 0.8

Distribution for six size groups in surface runoff modeling

21 5 16 20 13 25

UltraFines Distribution in BMP (74 microns and smaller)

41 23 15 9 6 3 2 1

Suspended Solids Distribution in BMP

0 0 0 0 0 0.5 0.8 1.2 1.5 2 9 25 60

Bottom Sediments Distribution in BMP

5 12 23 11 9 8 7 6 6 5 4 3 1

REMRATES.DAT: BMP Default Removal Rates for PSRM-QUAL

BMP type ->	DDB	DXDB	WDB	CW
Pollutants				
TSS	0.14	0.46	0.70	0.67
Cu	0	0.31	0.66	-0.21
Zn	-0.10	0.23	0.57	0.30
Lead	-0.05	0.46	0.66	0.61
Org1	0	0	0	0
Org2	0	0	0	0
TKN	0.10	0.30	0.32	0.16
NO2P3	0	0.18	0.49	0.52
TP	0.20	0.25	0.52	0.38
SP	0	-0.09	0	0.07
COD	0	0.21	0.52	0.27
BOD	0	0.35	0.34	-0.10

STDPARAM.DAT: Subarea Standard Parameters for PSRM-QUAL

1.	STDMN1	STDMN2	STDSF	STDMX	STDCTS		
	0.040	0.240	1.50	0.25	1.50		
2.	STDCN1	STDCN2	STDIAF	STDDS1	STDDS2	STDKS	STDIFSW
	98	70	0.10	0.06	0.00	0.33	0.20
3.	STDLU	STDMSL	STDISL	STDSWST	STDSWTI	STDSWFR	
	1	250.0	100.0	0.00	7.00	0.40	
4.	STDUK	STDUC	STDUP	STDSBK	STDCD	STDDFC	STDSFC
	0.20	0.03	0.40	6.0	0.40	0.20	0.40

APPENDIX B: Plotting File Data Using Commercial Software

The output results from PSRM-QUAL can be plotted using various graphical software packages. PSRM-QUAL input files (INP) and output files (OUT) have to be imported in the software package and then the data can be plotted. In this section, instructions are provided to plot PSRM-QUAL data using Microsoft Excel, Version 5.0, or Lotus 1-2-3 for MS-DOS, Release 2.2. Figure B1 is an example of a chart made in Microsoft Excel 5.0.

1 - Using Microsoft Excel, Version 5.0.

Open PSRM-QUAL Data File

1. On the Menu bar, select File and then Open.
2. In the Open window:
   - From the Drive and Directory boxes, select the appropriate drive and directory.
   - From the List Files of Type box, select "All Files (*.*)".
   - From the File Name box, select the appropriate file name. The Text Import Wizard window appears on the screen.
3. From the Text Import Wizard window:
   - First window: Click on Next.
   - Second window: Select how to parse the data in different columns. Follow the instructions to create, delete or move a column break. In the Data Preview box, use the vertical and horizontal scroll bar to verify that all the data are separate by column breaks. Click on Next.
   - Third window: Click on Finish. A spreadsheet appears on the screen with the data parsed in columns and rows. If the data are not correctly parsed, redo from the beginning.
4. To save the spreadsheet
   - Click on File from the Menu bar, and select Save As.
   - Enter a file name with the appropriate extension (".XLS" for an Excel file).

Create a Chart

1. Select data
   - Select the X data first, and then the Y data. To create a hydrograph, select the time data for X and the runoff data for Y. If more than one Y data series is selected, they all appear on the same chart. To highlight the X data, click on the cell that contains the first X data and hold down the left button of the mouse while dragging down until highlighting the last X data cell. Hold down the CTRL key and do the same thing to highlight the Y data.
2. On the Menu bar, choose Insert and then Chart - On This Sheet.
3. Click on the spreadsheet and drag with the mouse to draw a box where the chart will appear. This box can be moved and resized later on. The Chart Wizard Dialog box appears.
4. In the Chart Wizard Dialog box:
   - Click on Next.
   - Select the XY [Scatter] Chart Type, then click on Next.
   - Select the chart format, usually format 2 or 6, then click on Next.
   - Click on the appropriate buttons so that the following appears in the box:

     Data series in Columns
     - Use first 1 Row for X data
     - Use first 0 (or 1) Row for Legend Text (depending whether or not you selected the legend text for the X and Y data).
   - Click on Next.
   - Enter the Title for the Chart and X and Y axis. Click on Finish. The chart appears in a box on the spreadsheet.
5. Move the chart in the spreadsheet by clicking on it and then dragging. Resize the chart by clicking and dragging the black squares on the chart border.
6. To make any changes in the chart, double click on it and then use the Menu bar. Use the Insert menu to insert Legend, Title, Gridlines, etc. Double click on the axis, legend, title or data series to change their format. A Format Dialog box appears when you double click on the appropriate items. Choose the format in the dialog box.

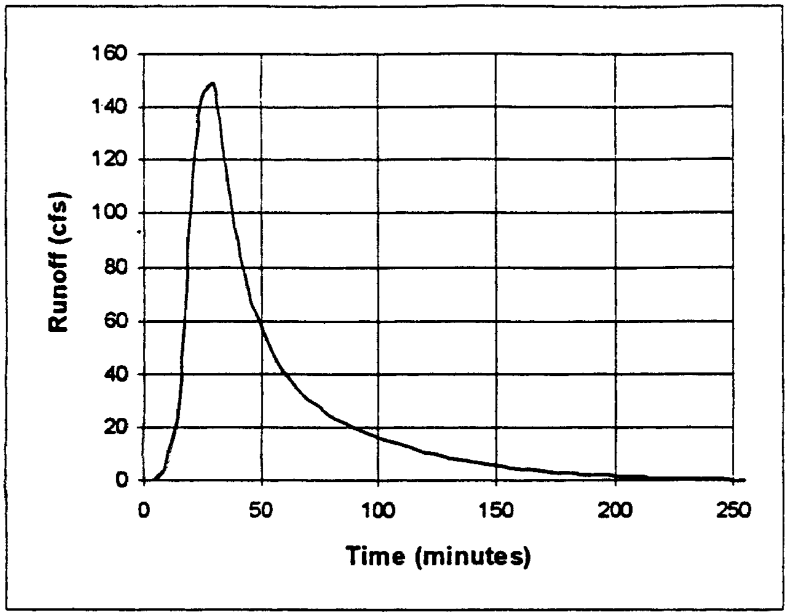

Figure B.1 Hydrograph plot created by using Excel

2 - Using Lotus 1-2-3 for MS-DOS, Release 2.2.

Open PSRM-QUAL Data File

1. In the Menu bar, select File, press Return.
2. In the File bar, select Import, press Return.
3. In the Import bar, select Text, press Return. A spreadsheet appears on the screen with the data parsed in different cells.

Create a Graph

1. In the Menu bar, select Graph. The Graph Setting window appears on the screen.
2. In the Graph Setting window:
   - Select the Type of Graph; to plot a hydrograph, the Graph Type is "Line".
   - Select the X-axis data by highlighting all the X data in the spreadsheet. To do so, put the cursor on the first X data, anchor the cursor by pressing "." (period), and then use the arrow keys until the X-axis data is highlighted.
   - Select the Y data range(s) (A, B, C,...) in a similar way.
   - Select Options to format the axes, the title, the legend, the gridlines, etc.
   - Select View to view the graph.
   - Select Save to save the graph in a file for printing.

APPENDIX C: Input INP File Example

The following is a listing of an INP file for PSRM-QUAL. The file is for a twelve subarea watershed applying a single event observed rainfall with four rain gages. The watershed contains a dry detention basin in subarea 6 and a wet detention basin in subarea 11.

Notice that the file contains blocks of data as described in Chapter 6. Only those data blocks needed for the analysis are included in the INP file. For instance, the example does not include an observed hydrograph, therefore an observed hydrograph data block is not present. In data blocks where standard parameters are used such as in the Subarea Parameters data block of Rainfall Losses, the first line will have an ID of "000" and list all the standard parameters as defined by the user during creation of the INP file. For all other row entries, the "-1" indicates that the parameter for the subarea in question is using the standard value. Any subarea that uses a non-standard value will replace the "-1" with the non-standard value. This feature is provided such that the user can easily identify those subareas not using standard values.

Once this file is created using the "File Create" routine in PSRM-QUAL, simple editing of a few parameters can be performed using MS-DOS EDIT. When changing the content of an INP file, the user must be careful to evaluate the effect of change in one parameter on others. For instance, if the user creates an INP file and later decides to lengthen the storm duration, by changing **HYDNPT** then the effect this change has on MaxHNPT and TotNPT must be considered and changed in the appropriate locations in the INP file. In addition, if the user wishes to insert another subarea, then **NSA** must be changed along with every data block in the Subarea Parameter section and Drainage Element section.

The number and order of lines in the INP file are very important. No text lines (lines not containing actual data) can be removed and when data lines are added, the appropriate counters must be adjusted accordingly. For instance, if you wish to add two more ESO points to the reservoir in subarea 11, you must also change the value of **NESO** in the leading line. IF you wish to add a BMP to subarea 9, the you must change the value of **NBMP** in the watershed elements data block, add a subarea ID number to the BMP identifier line (in the correct order), and add a complete BMP data block for the BMP of your choice.

Be aware that all BMP data blocks vary in structure depending on **BTYP**. The Rainfall Parameters data block also varies in structure depending on the value of **STOPT**. To get the exact structure of a BMP data block for a specific **BTYP** or rainfall data block for a specific **STOPT**, it is easiest to run the File Create routine in PSRM-QUAL for a single subarea with the **BTYP** or the **STOPT** of your choice and print the INP file. Then insert the needed block of text from this file into the file which you are editing.

```
PSRM-QUAL v95.0 INPUT FILE ================= Created:  12-07-1994 at 14:09:28
          QualFile      NHL        Filename
                1         2        sal2q.INP
    This is a test on PSRM-QUAL using the old 12 subarea test
    file found in the 93 version user's manual.
  WATERSHED Elements
      NSA       NST     STOPT      NPRT      NOBS      NPFP      NBMP      NORG
       12         1         0         4         0         0         2         2
    Subareas with a Hydrograph Printout
        1         6        11        12
    Subareas with a BMP
        6        11
  TIME PARAMETERS
     KWTI     HYDTI      RFTI      IETI   MaxHNPT    TotNPT
        1        10        10         0        24        24
    Storm    HYDNPT     IENPT
        1        24         0
  RAINFALL PARAMETERS
    Raingage Elements
      NRG      NNRG       NWG       EXW
        2         2         3         2
    Recording Raingage Data
      Event     Gage     RFNPT      RGST       XRG       YRG    RGNAME
        1         1         6         0        50      2100    Upper
                         0.07      0.33      1.00      1.00      0.40      0.60
        1         2         5        10       600       100    Lower
                         0.15      0.50      0.90      1.10      0.65
    Non-Recording Gage Data
      Event     Gage   RFTOTAL                 XRG       YRG    RGNAME
        1         3      3.60                  100        50    NR1
        1         4      4.20                  600      1800    NR2
```

SUBAREA PARAMETERS: ID# = 000 is standard parameter row

Geometry

ID#	XCG	YCG	AREA	LENG	SLOPE	FRIMP
1	400	1850	210	2290	0.060	0.20
2	400	1500	220	2400	0.040	0.30
3	800	1800	125	1815	0.050	0.25
4	1200	1350	40	970	0.100	0.10
5	950	1530	120	1740	0.030	0.35
6	700	1280	135	890	0.040	0.40
7	730	1050	142	1770	0.040	0.70
8	320	1030	125	1210	0.100	0.40
9	1120	1080	65	710	0.080	0.45
10	1040	830	80	1060	0.060	0.50
11	650	700	250	900	0.030	0.80
12	570	490	70	1050	0.030	0.75

Overland Flow Routing

ID#	MN1	MN2	SF
000	0.040	0.200	1.50
1	-1.000	-1.000	-1.00
2	-1.000	-1.000	-1.00
3	-1.000	-1.000	-1.00
4	-1.000	-1.000	-1.00
5	-1.000	-1.000	-1.00
6	-1.000	-1.000	-1.00
7	-1.000	-1.000	-1.00
8	-1.000	-1.000	-1.00
9	-1.000	-1.000	-1.00
10	-1.000	-1.000	-1.00
11	-1.000	-1.000	-1.00
12	-1.000	-1.000	-1.00

Rainfall Losses

ID#	CN1	CN2	IAF	DS1	DS2	KS	IFSW
000	99	70	0.10	0.06	0.00	0.33	0.00
1	-1	60	-1.00	-1.00	-1.00	-1.00	-1.00
2	-1	65	-1.00	-1.00	-1.00	-1.00	-1.00
3	-1	60	-1.00	-1.00	-1.00	-1.00	-1.00
4	-1	-1	-1.00	-1.00	-1.00	-1.00	-1.00
5	-1	-1	-1.00	-1.00	-1.00	-1.00	-1.00
6	-1	-1	-1.00	-1.00	-1.00	-1.00	-1.00
7	-1	75	-1.00	-1.00	-1.00	-1.00	-1.00
8	-1	60	-1.00	-1.00	-1.00	-1.00	-1.00
9	-1	65	-1.00	-1.00	-1.00	-1.00	-1.00
10	-1	-1	-1.00	-1.00	-1.00	-1.00	-1.00
11	-1	75	-1.00	-1.00	-1.00	-1.00	-1.00
12	-1	75	-1.00	-1.00	-1.00	-1.00	-1.00

Landuse & Impervious Sediment Loading

ID#	LU	MSL	ISL	SWST	SWTI	SWFR
000	1	250.0	200.0	0.00	7.00	0.40
1	-1	-1.0	-1.0	-1.00	-1.00	-1.00
2	-1	-1.0	-1.0	-1.00	-1.00	-1.00
3	-1	-1.0	-1.0	-1.00	-1.00	-1.00
4	-1	-1.0	-1.0	-1.00	-1.00	-1.00
5	-1	-1.0	-1.0	-1.00	-1.00	-1.00
6	-1	-1.0	-1.0	-1.00	-1.00	-1.00
7	-1	-1.0	-1.0	-1.00	-1.00	-1.00
8	-1	-1.0	-1.0	-1.00	-1.00	-1.00
9	-1	-1.0	-1.0	-1.00	-1.00	-1.00
10	-1	-1.0	-1.0	-1.00	-1.00	-1.00
11	-1	-1.0	-1.0	-1.00	-1.00	-1.00
12	-1	-1.0	-1.0	-1.00	-1.00	-1.00

Pervious Sediment Loading; Sediment Dislodging & Wash-Off

ID#	UK	UC	UP	SBK	CD	DFC	SFC
000	0.20	0.03	0.40	6.00	0.40	0.20	0.40
1	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
2	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
3	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
4	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
5	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
6	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
7	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
8	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
9	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
10	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
11	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
12	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

Organic Pollutants

ID#	ORGCONC	ORGNAME
1	0.120	DDT
2	0.760	PCB

DRAINAGE ELEMENT PARAMETERS: ID# = 000 is standard parameter row

ID#	CAP	PT	MX	CTS	CDE1	CDE2	CDE3
000			0.30	1.50			
1	200.0	5.0	-1.00	-1.00	0	0	0
2	540.0	5.0	-1.00	-1.00	1	0	0
3	200.0	4.0	-1.00	-1.00	0	0	0
4	80.0	4.5	-1.00	-1.00	0	0	0
5	500.0	3.5	-1.00	-1.00	3	4	0
6	1000.0	5.5	-1.00	-1.00	2	5	0
7	1200.0	4.5	-1.00	-1.00	6	0	0
8	320.0	4.0	-1.00	-1.00	0	0	0
9	320.0	4.0	-1.00	-1.00	0	0	0
10	600.0	5.5	-1.00	-1.00	9	0	0
11	1800.0	3.0	-1.00	-1.00	7	8	10
12	2400.0	10.0	-1.00	-1.00	11	0	0

```
BMP DATA --- BTYP:  ddb = 1  dxdb = 2  wdb = 3  cw = 4  ib = 5  it = 6
  BmpID    SArea     BTYP    REMOPT
      1        6        1         2
            NESO     IWSE      ELEV  STORAGE  OUTFLOW
               8    120.0     120.0     0.00      0.0
                              122.0    10.00     40.0
                              124.0    20.00    110.0
                              127.0    35.00    230.0
                              130.0    50.00    300.0
                              133.0    65.00    350.0
                              136.0    85.00    380.0
                              140.0   110.00    420.0
           BOTEL      SCN
           120.0        5
          BOTSLP   BOTEFL     BOTMN  VBOTSED
           0.005      550     0.240      300
          GRSPCG    GRHGT    STGDIM
           1.000     6.00      6.00
  BmpID    SArea     BTYP    REMOPT
      2       11        3         2
            NESO     IWSE      ELEV  STORAGE  OUTFLOW
               8     82.0      80.0     0.00      0.0
                               82.0    15.00      0.0
                               84.0    30.00     90.0
                               86.0    40.00    150.0
                               88.0    55.00    260.0
                               90.0    80.00    300.0
                               92.0    95.00    330.0
                               94.0   118.00    700.0
            TSSo     TKNo    NO2P3o      TPo      SPo     CODo     BODo
          25.000    5.000     1.500    2.000    0.500   15.000    9.000
           BOTEL      SCN
            80.0        5
          BOTSLP   BOTEFL     BOTMN  VBOTSED
           0.005      500     0.100      700
-- End of File --
```

APPENDIX D: Output OUT File Example

The following listing is the OUT file for the INP file shown in Appendix C.

```
+-----------------------------------+
|                                   |
|        -+-   PSRM-QUAL  -+-       |
|                                   |
|  PENN STATE RUNOFF QUALITY MODEL  |
|                                   |
|          Version  95.0            |
|                                   |
+-----------------------------------+

  Input File: SA12Q.INP
 Output File: SA12Q.OUT

    QualFile: YES     QualRun: YES     Sensitivity: NO

                    HYDROGRAPH OUTPUT for SUBAREA    1
          Net Rain =  1.312 inches        Runoff =  1.238 inches
Time   Rain    Losses   Runoff   Reservoir/BMP    MainQ    SurchQ   ObsHyd
 min  inches  inches     cfs   Qin,cfs  WSElev    cfs       cfs      cfs
-------------------------------------------------------------------------
  10   0.083   0.083     0.0                       0.0       0.0
  20   0.476   0.411     8.8                       8.8       0.0
  30   1.664   1.261   115.4                     115.4       0.0
  40   2.853   1.884   259.4                     200.0      59.4
  50   3.329   2.090   220.6                     200.0      20.6
  60   4.042   2.363   236.9                     200.0      36.9
  70   4.042   2.385   155.0                     155.0       0.0
  80   4.042   2.407   107.5                     107.5       0.0
  90   4.042   2.429    82.8                      82.8       0.0
 100   4.042   2.451    67.3                      67.3       0.0
 110   4.042   2.473    56.5                      56.5       0.0
 120   4.042   2.495    48.2                      48.2       0.0
 130   4.042   2.517    41.2                      41.2       0.0
 140   4.042   2.539    35.2                      35.2       0.0
 150   4.042   2.561    30.0                      30.0       0.0
 160   4.042   2.583    25.5                      25.5       0.0
 170   4.042   2.605    21.5                      21.5       0.0
 180   4.042   2.627    18.0                      18.0       0.0
 190   4.042   2.648    15.0                      15.0       0.0
 200   4.042   2.665    12.4                      12.4       0.0
 210   4.042   2.683    10.1                      10.1       0.0
 220   4.042   2.701     8.1                       8.1       0.0
```

230	4.042	2.717	6.4		6.4	0.0
240	4.042	2.730	5.0		5.0	0.0

POLLUTANT OUTPUT For SUBAREA 1

Time min	TSS ppm	Cu ppb	Zn ppb	Pb ppb	DDT ppt	PCB ppt	TKN ppb	NO2+3 ppb	TP ppb	SP ppb	COD ppm	BOD ppm
10	0	0	0	0	0	0	0	0	0	0	0	0
20	1204	394	1614	1722	145	915	22640	8779	4564	1710	871	119
30	570	186	764	815	68	433	10714	4154	2160	809	412	56
40	52	17	70	75	6	40	987	383	199	75	38	5
50	107	35	144	154	13	82	2019	783	407	153	78	11
60	196	64	262	280	23	149	3677	1426	741	278	141	19
70	292	96	392	418	35	222	5498	2132	1108	415	211	29
80	399	131	535	571	48	303	7506	2911	1513	567	289	40
90	482	158	646	689	58	366	9057	3512	1826	684	348	48
100	543	177	727	776	65	412	10203	3956	2057	771	392	54
110	581	190	779	831	70	442	10929	4238	2203	825	420	58
120	605	198	811	865	73	460	11372	4410	2293	859	437	60
130	619	202	829	885	74	470	11632	4511	2345	879	447	61
140	626	205	839	895	75	476	11770	4564	2373	889	453	62
150	628	205	842	899	75	478	11814	4581	2382	892	454	62
160	626	205	839	896	75	476	11775	4566	2374	889	453	62
170	620	203	830	886	74	471	11649	4517	2348	880	448	61
180	607	198	813	868	73	461	11405	4423	2299	861	439	60
190	611	200	819	874	73	464	11485	4453	2315	867	442	60
200	612	200	820	875	73	465	11498	4458	2318	868	442	61
210	606	198	812	867	73	461	11398	4420	2298	861	438	60
220	591	193	792	845	71	449	11110	4308	2240	839	427	59
230	559	183	749	799	67	425	10509	4075	2119	794	404	55
240	496	162	665	710	60	377	9332	3618	1881	705	359	49
EMCs	332	109	445	475	40	252	6243	2421	1259	472	240	33

ppm = parts per million ppt = parts per trillion
ppb = parts per billion

HYDROGRAPH OUTPUT for SUBAREA 6

Net Rain = 2.222 inches Runoff = 2.216 inches

Time min	Rain inches	Losses inches	Runoff cfs	Reservoir/BMP Qin,cfs	WSElev	MainQ cfs	SurchQ cfs	ObsHyd cfs
10	0.081	0.081	0.0	0.0	120.00	0.0	0.0	
20	0.463	0.338	22.2	34.9	120.05	0.9	0.0	
30	1.621	0.883	260.1	450.7	120.70	13.9	0.0	
40	2.778	1.235	402.3	1097.7	122.72	65.2	0.0	
50	3.241	1.345	269.1	1337.1	125.74	179.4	0.0	
60	3.936	1.487	314.2	1330.9	128.79	271.8	0.0	
70	3.936	1.503	177.5	1089.1	131.31	321.8	0.0	
80	3.936	1.520	111.4	740.3	132.90	348.4	0.0	
90	3.936	1.536	76.1	486.9	133.47	354.7	0.0	

100	3.936	1.553	54.3	377.6	133.63	356.3	0.0
110	3.936	1.569	39.6	293.6	133.58	355.8	0.0
120	3.936	1.586	29.2	240.2	133.40	354.0	0.0
130	3.936	1.602	21.7	197.9	133.13	351.3	0.0
140	3.936	1.619	16.2	165.1	132.71	345.2	0.0
150	3.936	1.635	12.0	138.1	132.19	336.5	0.0
160	3.936	1.649	8.9	115.7	131.62	327.1	0.0
170	3.936	1.662	6.5	96.8	131.03	317.1	0.0
180	3.936	1.675	4.7	80.9	130.41	306.9	0.0
190	3.936	1.684	3.3	67.4	129.79	295.1	0.0
200	3.936	1.694	2.2	55.9	129.17	280.5	0.0
210	3.936	1.701	1.4	46.3	128.55	266.3	0.0
220	3.936	1.708	0.9	38.1	127.96	252.3	0.0
230	3.936	1.711	0.5	31.2	127.37	238.7	0.0
240	3.936	1.714	0.4	25.4	126.82	222.7	0.0

BMP POLLUTANT OUTPUT for SUBAREA 6

Time	TSS(ppm)		Cu(ppb)		Zn(ppb)		Pb(ppb)		DDT(ppt)		PCB(ppt)	
min	in	out	in	out	in	out	in	out	in	out	in	out
10	0	0	0	0	0	0	0	0	0	0	0	0
20	2784	935	911	306	3731	1253	3982	1337	334	112	2116	710
30	716	368	234	120	960	493	1024	527	86	44	544	280
40	77	159	25	52	104	212	111	227	9	19	59	121
50	87	101	28	33	116	136	124	145	10	12	66	77
60	151	98	49	32	202	131	216	140	18	12	115	74
70	141	103	46	34	189	139	202	148	17	12	107	79
80	168	108	55	35	225	144	240	154	20	13	128	82
90	217	114	71	37	291	152	311	163	26	14	165	86
100	242	120	79	39	324	161	346	172	29	14	184	92
110	270	127	88	41	361	170	386	181	32	15	205	96
120	284	133	93	43	381	178	407	190	34	16	216	101
130	296	138	97	45	397	185	424	198	36	17	225	105
140	303	143	99	47	406	192	434	204	36	17	231	109
150	307	147	100	48	411	197	439	211	37	18	233	112
160	307	151	100	49	411	202	439	216	37	18	233	115
170	307	154	100	50	411	207	439	221	37	19	233	117
180	304	157	99	51	407	211	435	225	36	19	231	119
190	304	160	99	52	408	214	435	228	36	19	231	121
200	303	162	99	53	406	217	434	232	36	19	230	123
210	298	164	97	54	400	220	426	234	36	20	227	125
220	288	166	94	54	385	222	411	237	35	20	219	126
230	272	167	89	55	365	224	390	239	33	20	207	127
240	247	168	81	55	331	225	354	240	30	20	188	128
EMCs	206	139	68	45	277	186	295	199	25	17	157	106

BMP POLLUTANT OUTPUT for SUBAREA 6

Time	TKN(ppb)		NO2+3(ppb)		TP(ppb)		SP(ppb)		COD(ppm)		BOD(ppm)	
min	in	out	in	out	in	out	in	out	in	out	in	out
10	0	0	0	0	0	0	0	0	0	0	0	0
20	52348	29159	20299	20292	10553	4623	3954	3953	2013	2010	276	275
30	13468	10808	5223	7198	2715	1759	1017	1402	518	713	71	98
40	1501	4731	564	3190	305	764	110	621	56	316	8	43
50	1675	2767	634	1740	340	465	123	339	63	172	9	24
60	2925	2426	1099	1389	595	427	214	271	109	137	15	19
70	2654	2420	1029	1298	535	438	200	253	102	128	14	18
80	3162	2442	1226	1262	637	448	239	246	122	125	17	17
90	4086	2530	1585	1275	824	469	309	248	157	126	22	17
100	4552	2643	1765	1307	918	493	344	255	175	129	24	18
110	5070	2754	1966	1342	1022	517	383	261	195	132	27	18
120	5345	2859	2073	1377	1078	539	404	268	206	136	28	19
130	5573	2955	2161	1410	1124	559	421	275	214	139	29	19
140	5703	3041	2211	1439	1150	577	431	280	219	141	30	19
150	5771	3116	2238	1465	1163	592	436	285	222	144	30	20
160	5766	3183	2236	1487	1162	606	436	290	222	146	30	20
170	5768	3241	2237	1506	1163	619	436	293	222	148	30	20
180	5715	3291	2216	1522	1152	629	432	297	220	149	30	20
190	5717	3336	2217	1536	1153	639	432	299	220	150	30	21
200	5701	3374	2211	1548	1149	647	431	302	219	151	30	21
210	5605	3407	2174	1558	1130	654	423	303	216	152	30	21
220	5405	3434	2096	1566	1090	659	408	305	208	153	28	21
230	5121	3455	1986	1572	1032	664	387	306	197	153	27	21
240	4649	3470	1803	1575	937	667	351	307	179	153	24	21
EMCs	3908	3022	1505	1476	789	567	293	288	149	145	20	20

ppm = parts per million ppb = parts per billion

ppt = parts per trillion

WARNING: DETENTION FACILITY IN SUBAREA 11 IS OVERFLOWING.
COMPUTATIONS ARE EXTRAPOLATED.

HYDROGRAPH OUTPUT for SUBAREA 11

Net Rain = 2.919 inches Runoff = 2.904 inches

Time	Rain	Losses	Runoff	Reservoir/BMP		MainQ	SurchQ	ObsHyd
min	inches	inches	cfs	Qin,cfs	WSElev	cfs	cfs	cfs
10	0.161	0.126	2.5	6.5	82.01	0.3	0.0	
20	0.696	0.258	176.2	266.7	82.25	11.1	0.0	
30	1.659	0.389	826.2	1352.8	83.65	74.5	0.0	
40	2.837	0.488	1340.3	2597.6	87.66	241.3	0.0	
50	3.533	0.531	1045.6	2641.1	90.63	309.5	0.0	
60	3.533	0.536	435.3	1637.6	93.16	544.3	0.0	
70	3.533	0.542	213.8	935.0	93.96	692.3	0.0	
80	3.533	0.547	121.5	717.2	94.10	719.0	0.0	
90	3.533	0.553	78.5	609.0	94.04	707.8	0.0	

100	3.533	0.558	54.4	539.0	93.90	681.1	0.0
110	3.533	0.564	39.4	490.2	93.72	647.9	0.0
120	3.533	0.569	29.3	455.9	93.53	613.0	0.0
130	3.533	0.575	22.2	429.9	93.35	579.1	0.0
140	3.533	0.580	17.1	408.9	93.17	547.2	0.0
150	3.533	0.586	13.2	389.9	93.01	517.7	0.0
160	3.533	0.591	10.3	371.2	92.87	490.4	0.0
170	3.533	0.595	8.1	353.9	92.73	464.9	0.0
180	3.533	0.599	6.4	338.1	92.60	441.2	0.0
190	3.533	0.603	5.0	323.1	92.48	419.1	0.0
200	3.533	0.606	3.9	307.7	92.37	398.4	0.0
210	3.533	0.609	3.1	291.1	92.26	378.7	0.0
220	3.533	0.611	2.5	274.6	92.16	359.6	0.0
230	3.533	0.613	2.0	259.2	92.06	341.1	0.0
240	3.533	0.614	1.6	244.0	91.94	329.1	0.0

BMP POLLUTANT OUTPUT for SUBAREA 11

Time	TSS(ppm)		Cu(ppb)		Zn(ppb)		Pb(ppb)		DDT(ppt)		PCB(ppt)	
min	in	out	in	out	in	out	in	out	in	out	in	out
10	1678	27	549	9	2248	36	2399	39	201	3	1275	20
20	2046	137	669	45	2742	183	2926	195	246	16	1555	104
30	157	166	51	54	211	223	225	238	19	20	119	126
40	37	100	12	33	50	134	53	143	4	12	28	76
50	80	78	26	26	107	105	114	112	10	9	61	59
60	97	77	32	25	130	103	139	110	12	9	74	58
70	134	80	44	26	180	107	192	114	16	10	102	61
80	142	83	46	27	190	112	203	119	17	10	108	63
90	140	86	46	28	187	116	200	124	17	10	106	66
100	138	89	45	29	185	119	198	127	17	11	105	68
110	138	91	45	30	185	122	197	130	17	11	105	69
120	138	93	45	30	185	125	197	133	17	11	105	71
130	139	95	45	31	186	127	199	136	17	11	106	72
140	141	97	46	32	188	130	201	139	17	12	107	74
150	142	99	46	32	190	132	203	141	17	12	108	75
160	143	100	47	33	192	134	205	143	17	12	109	76
170	145	102	48	33	195	137	208	146	17	12	110	77
180	148	104	48	34	198	139	211	148	18	12	112	79
190	149	105	49	34	200	141	213	150	18	13	113	80
200	150	107	49	35	201	143	215	152	18	13	114	81
210	152	108	50	35	204	145	217	154	18	13	115	82
220	154	109	50	36	206	147	220	156	18	13	117	83
230	155	111	51	36	207	148	221	158	19	13	118	84
240	154	112	50	37	206	150	220	160	18	13	117	85
EMCs	144	95	47	31	193	127	206	136	17	11	109	72

BMP POLLUTANT OUTPUT for SUBAREA 11

Time	TKN(ppb)		NO2+3(ppb)		TP(ppb)		SP(ppb)		COD(ppm)		BOD(ppm)	
min	in	out	in	out	in	out	in	out	in	out	in	out
10	31546	2022	12232	2036	6360	390	2383	1007	1213	19	166	9
20	38513	4631	14966	3461	7760	840	2915	1215	1484	181	203	31
30	2994	5025	1192	3460	599	885	232	999	118	245	16	37
40	776	2978	323	2032	153	519	63	557	32	153	4	23
50	1564	2166	652	1391	309	384	127	365	65	109	9	16
60	1925	2001	821	1214	378	360	160	306	81	99	11	14
70	2689	2002	1166	1175	525	363	227	288	115	98	16	14
80	2870	2052	1266	1178	557	374	247	283	125	100	17	14
90	2859	2098	1280	1185	552	384	249	281	126	102	17	14
100	2848	2135	1291	1191	548	392	251	279	127	103	17	15
110	2860	2168	1308	1198	549	399	255	277	129	105	18	15
120	2874	2199	1323	1204	550	405	258	276	130	106	18	15
130	2907	2229	1343	1211	556	411	262	275	132	107	18	15
140	2940	2258	1360	1218	562	417	265	275	134	108	18	15
150	2964	2286	1371	1225	567	423	267	274	135	109	18	15
160	2994	2313	1384	1232	572	428	270	274	136	110	19	15
170	3036	2340	1401	1240	581	433	273	274	137	111	19	16
180	3078	2366	1417	1247	589	439	276	274	139	113	19	16
190	3106	2392	1426	1255	595	444	278	274	139	114	19	16
200	3122	2417	1429	1262	599	449	278	274	140	114	19	16
210	3152	2440	1439	1269	605	454	280	274	140	115	19	16
220	3183	2463	1450	1276	612	458	282	274	141	116	19	16
230	3203	2485	1456	1282	616	463	284	275	142	117	19	16
240	3183	2505	1444	1288	612	467	281	275	140	118	19	16
EMCs	2868	2273	1226	1262	562	417	239	294	121	109	17	16

ppm = parts per million ppb = parts per billion
ppt = parts per trillion

HYDROGRAPH OUTPUT for SUBAREA 12

Net Rain = 2.707 inches Runoff = 2.687 inches

Time	Rain	Losses	Runoff	Reservoir/BMP		MainQ	SurchQ	ObsHyd
min	inches	inches	cfs	Qin,cfs	WSElev	cfs	cfs	cfs
10	0.156	0.126	0.5			0.8	0.0	
20	0.676	0.278	37.3			43.8	0.0	
30	1.612	0.438	188.3			237.9	0.0	
40	2.755	0.561	330.9			511.9	0.0	
50	3.431	0.614	272.2			577.5	0.0	
60	3.431	0.621	122.6			569.4	0.0	
70	3.431	0.628	62.4			731.9	0.0	
80	3.431	0.635	37.5			754.4	0.0	
90	3.431	0.642	25.0			738.3	0.0	
100	3.431	0.649	17.8			707.9	0.0	
110	3.431	0.655	13.2			671.4	0.0	
120	3.431	0.662	10.0			633.6	0.0	

130	3.431	0.669	7.8	596.9	0.0
140	3.431	0.676	6.1	562.7	0.0
150	3.431	0.683	4.8	531.2	0.0
160	3.431	0.690	3.8	502.2	0.0
170	3.431	0.695	3.0	475.4	0.0
180	3.431	0.701	2.4	450.5	0.0
190	3.431	0.706	1.9	427.5	0.0
200	3.431	0.711	1.5	406.1	0.0
210	3.431	0.715	1.2	385.7	0.0
220	3.431	0.719	1.0	366.2	0.0
230	3.431	0.721	0.8	347.3	0.0
240	3.431	0.724	0.6	332.5	0.0

POLLUTANT OUTPUT For SUBAREA 12

Time min	TSS ppm	Cu ppb	Zn ppb	Pb ppb	DDT ppt	PCB ppt	TKN ppb	NO2+3 ppb	TP ppb	SP ppb	COD ppm	BOD ppm
10	702	229	940	1003	84	533	13703	5738	2756	1324	507	72
20	1430	468	1916	2045	172	1087	27402	11047	5501	2289	1054	146
30	188	61	251	268	23	143	4121	2071	791	505	175	25
40	53	17	72	76	6	41	1524	1004	269	272	77	11
50	47	15	63	68	6	36	1263	785	226	204	62	9
60	78	26	105	112	9	59	2001	1194	362	299	98	14
70	78	26	105	112	9	60	1951	1133	355	277	95	14
80	82	27	110	117	10	62	2000	1140	365	273	97	14
90	85	28	113	121	10	64	2045	1149	375	272	99	14
100	87	28	117	124	10	66	2081	1156	382	270	100	14
110	89	29	119	127	11	68	2113	1164	389	269	102	14
120	91	30	122	130	11	69	2145	1171	395	268	103	15
130	93	30	125	133	11	71	2176	1180	401	268	104	15
140	95	31	127	136	11	72	2207	1189	408	268	106	15
150	97	32	129	138	12	73	2237	1197	414	268	107	15
160	98	32	132	141	12	75	2265	1206	419	268	108	15
170	100	33	134	143	12	76	2293	1214	425	268	109	15
180	102	33	136	145	12	77	2320	1223	430	268	110	15
190	103	34	138	147	12	78	2347	1231	436	269	111	16
200	105	34	140	150	13	80	2373	1239	441	269	112	16
210	106	35	142	152	13	81	2397	1246	446	269	113	16
220	107	35	144	154	13	82	2419	1253	450	269	114	16
230	109	36	146	155	13	83	2440	1259	454	270	115	16
240	111	36	148	158	13	84	2479	1275	462	272	116	16
EMCs	96	31	129	137	12	73	2247	1218	416	281	106	15

ppm = parts per million ppt = parts per trillion

ppb = parts per billion

OUTFLOW SUMMARY TABLE

Subarea No.	Rainfall cfs-hrs	Runoff cfs-hrs	Subarea Qpeak (cfs)	Subarea Tpeak (min)	Subarea TSSemc (mg/l)	Global Qpeak (cfs)	Global Tpeak (min)	Global TSSemc (mg/l)
1	848.9	262.1	259.4	40	332	259.4	40	332
2	878.8	357.7	344.4	40	173	578.0	50	237
3	517.9	188.3	210.0	40	224	210.0	40	224
4	155.4	59.7	74.5	60	615	74.5	60	615
5	483.2	241.1	248.7	40	122	468.6	50	221
6	531.3	301.7	402.3	40	122	356.3	100	139
7	539.7	410.5	636.9	40	106	694.5	50	131
8	470.3	229.5	386.9	40	330	386.9	40	330
9	247.1	141.5	246.1	40	206	246.1	40	206
10	291.2	179.7	298.8	40	158	521.3	40	179
11	883.2	732.0	1340.3	40	93	719.0	80	95
12	240.2	189.6	330.9	40	97	754.4	80	96

Surcharge occurred in the following subareas: 1 2 3 8

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APPENDIX E: Worksheets

Worksheets for PSRMQUAL v95.0 are presently not available.

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